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National Aeronautics and Space Administration

Electronic Components and Circuits

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02-07 July 2002

INTRODUCTION

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National Aeronautics and
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July 2002
02-07

5 Electronic Components and Circuits

9 Electronic Systems

15 Physical Sciences

23 Materials

27 Computer Programs

31 Mechanics

37 Machinery

41 Fabrication Technology

45 Mathematics and Information Sciences

49 Life Sciences

4

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Electronic Components and Circuits

Hardware, Techniques, and Processes

7 Evolutionary Automated Synthesis of Electronic Circuits
8 Designing Reconfigurable Antennas Through Hardware Evolution

6

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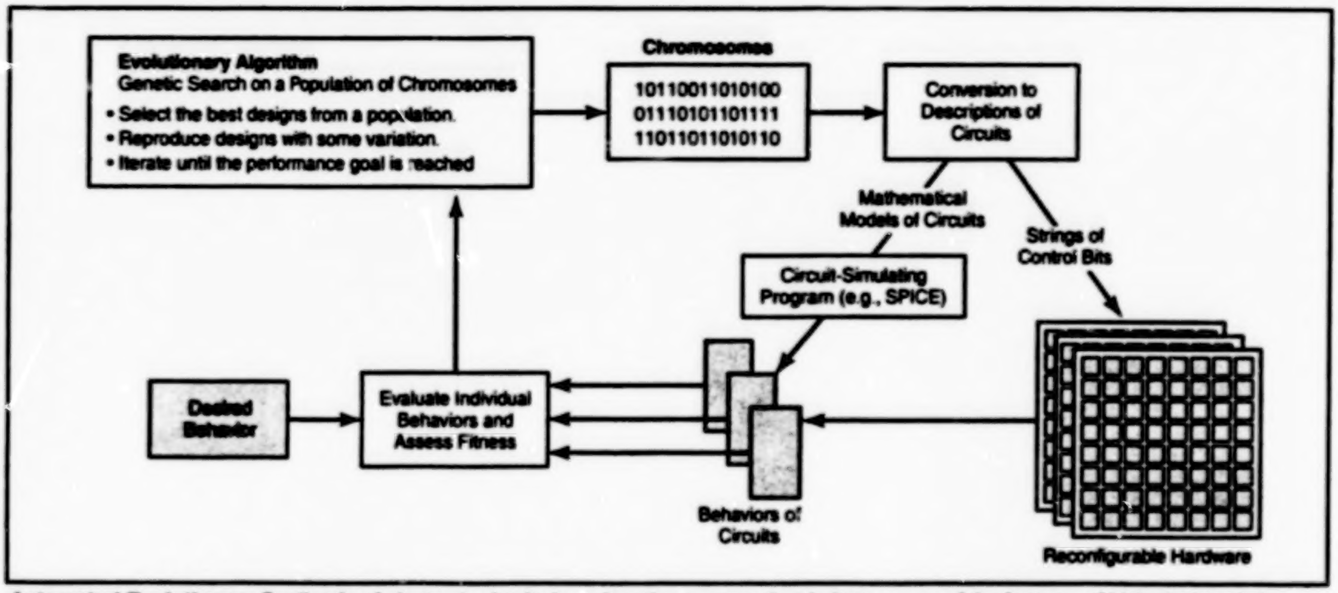
Evolutionary Automated Synthesis of Electronic Circuits

A genetic algorithm causes circuits to evolve toward a desired behavior.

NASA's Jet Propulsion Laboratory, Pasadena, California



Automated Evolutionary Synthesis of electronic circuits is an iterative process that imitates some of the features of biological evolution.

A method of automated synthesis of analog and/or digital electronic circuits involves evolution, either in software simulations or in hardware, directly on integrated-circuit chips. "Evolution" is used here in a quasi-genetic sense, signifying the construction and testing of a sequence of populations of circuits that function as incrementally better solutions of a given design problem. The evolution is guided by a search-and-optimization algorithm (in particular, a genetic algorithm) that operates in the space of possible circuits to find a circuit that exhibits the desired behavior.

In comparison with evolution by use of software circuit simulations, evolution in hardware can speed the search for a solution circuit by a few orders of magnitude. Moreover, because software simulations rely on mathematical circuit models of limited accuracy, a solution evolved in software can behave differently when downloaded in programmable hardware; such mismatches are avoided when evolution takes place directly in hardware.

A prior version of automated synthesis of electronic circuits in hardware was discussed in "Reconfigurable Arrays of Transistors for Evolvable Hardware" (NPO-20078), *NASA Tech Briefs*, Vol. 25, No. 2, (February 2001), page 36. To recapitulate: Very-large-scale integrated (VLSI) circuits would contain electronically reconfigurable arrays of transistors. Under the direction of genetic and/or other evolutionary algorithms, the configurations and thus the functionalities of the circuits would be made to evolve until at least one circuit exhibited a desired behavior or adapted to the environment in a prescribed way. Evolution would include selective, repetitive connection and/or disconnection of transistors, amplifiers, inverters, and/or other circuit building blocks.

The present version of automated synthesis of electronic circuits in either software simulation or hardware is based on the same general concept as that of the prior version, the main differences lying in the details of implementation. The figure schematically depicts the main steps of an automated evolutionary synthesis according to the present method. In the first step, a mathematical representation of a population of circuits (in this context, analogous to chromosomes) is generated randomly. The chromosomes are then converted into either (1) mathematical models of circuits or (2) strings of control bits that are downloaded to programmable hardware (if the circuits are to be evaluated directly in hardware). In the mathematical-model case, the simulation program compares the behaviors of the models with the desired behavior and the evolution is said to be "extrinsic"; in the programmable-hardware case, the physical behaviors of the hardware are compared with the desired behavior and the evolution is said to be "intrinsic."

In either the intrinsic or the extrinsic case, the circuits are ranked according to how close their behaviors come to the desired behavior. A new population of circuits is generated from a selected pool of best circuits in the previous generation, subject to a such genetic operators as chromosome crossover and mutation. The process is repeated for many generations, yielding progressively better circuits. The criterion for stopping the evolution can be the reduction of error below a certain threshold, or reaching a predetermined number of generations. One or several solutions may be found among the individuals of the last generation.

The viability of this method has been demonstrated on a sequence of software prototypes. In a proposed hardware implementation, the basic circuit elements would be an array of metal oxide/semiconductor field-effect transistors interconnected via programmable switches. The circuit topology would be a function of the switch states (off or on), which would be specified by the strings of control bits. This programmable array of transistors could be modular, and modules could be cascaded and/or expanded to obtain circuits of greater complexity.

This work was done by Adrian Stoica and Carlos Salazar-Lazaro of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Management Office–JPL [see page 1]. Refer to NPO-20535.

Designing Reconfigurable Antennas Through Hardware Evolution

This method offers potential advantages over computational simulation.

NASA's Jet Propulsion Laboratory, Pasadena, California

In a proposed method of designing a reconfigurable antenna, the design would be optimized through evolution in hardware. The proposed method would be a specific instance of an emerging general method of automated synthesis of electronic circuits in hardware. Other specific instances of the general method were described in two prior *NASA Tech Briefs* articles: "Reconfigurable Arrays of Transistors for Evolvable Hardware" (NPO-20078), February 2001; and "Evolutionary Automated Synthesis of Electronic Circuits" (NPO-20535), this issue. To recapitulate: Under the direction of genetic and/or other evolutionary algorithms, the configurations and thus the functionalities of circuits would be made to evolve until at least one circuit exhibited a desired behavior. Evolution would include selective, repetitive connection and/or disconnection of transistors, amplifiers, inverters, and/or other circuit building blocks.

According to the proposed method, a reconfigurable antenna in a basic initial configuration would be placed on an antenna test range equipped for testing at the frequency or frequencies of interest. A computer outside the test range would be connected to interface circuits that would, in turn, be connected to (1) the test equipment (transmitters and receivers) on the range and (2) wires through which the computer could control the configuration of the antenna.

The computer would execute software that would include one or more automated-optimization algorithms plus driver-interface software for controlling the antenna configuration and the test equipment. Following initial activation, the software would go through the optimization process, controlling the test equipment and the antenna configuration as needed to produce an optimized configuration for each set of desired electromagnetic properties.

The only other method of automated design by use of an optimization algorithm involves computational simulation of performance instead of testing of a real physical implementation. The proposed method does not involve computational simulation and is expected to surpass the method that involves computational simulation; this is because the results of testing a real physical implementation are inherently valid and more accurate than are results obtained through computational simulation. In addition, optimization by use of the proposed method is expected to take much less time than does optimization by use of a computational simulation of reasonable fidelity. Moreover, unlike in the computational-simulation method, there would be no need to try to validate the simulated results with a physical test — an undertaking that usually entails manual re-optimization of the design to obtain the same performance from the physical device as from the simulated one.

This work was done by Adrian Stoica and Derek Linden of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*
NPO-20666

Electronic Systems

Hardware, Techniques, and Processes

11 Artificial Neural Networks for Organizing Sensor Webs
12 System Locates Buried Objects Marked by Electromagnetic Tags
12 Advanced Capacitive-Sensor Turbine-Blade-Monitoring System
13 System Mimics an Avionic Multiplexer/Demultiplexer
14 FPGA-Based Test Bench for Nonvolatile Electronic Memories

Books and Reports

14 Deep-Space Ranging Using Pseudonoise Codes

Artificial Neural Networks for Organizing Sensor Webs

The proven organizational abilities of natural neural networks would be exploited.

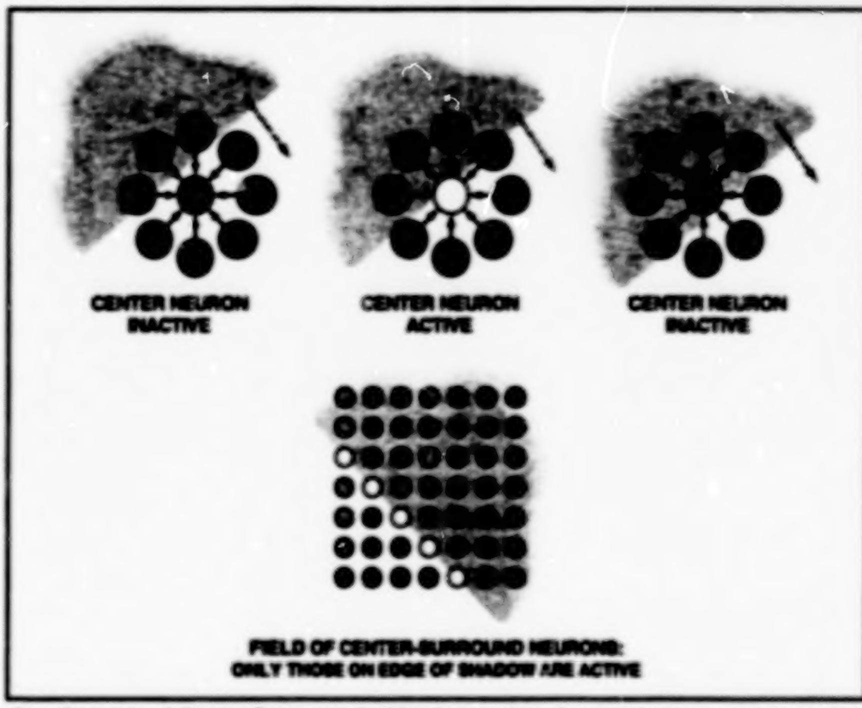
NASA's Jet Propulsion Laboratory, Pasadena, California

A scheme for organizing and controlling sensor webs is based on artificial neural networks. [Sensor webs were described in "Sensor Webs" (NPO-20616), *NASA Tech Briefs*, October 1999. To recapitulate: Sensor webs are collections of sensor pods that could be scattered over land or water areas or other regions of interest to gather data on spatial and temporal patterns of relatively slowly changing physical, chemical, or biological phenomena in those regions. Each sensor pod is a node in a data-gathering/data-communication network that spans a region of interest.] The present scheme would exploit communication and information-processing concepts that have enabled biological neural networks to organize and control large numbers of biological sensors, as proven in nature during the last billion years or longer.

From one perspective, the scheme could be characterized as one of designing artificial neural networks to have architectures approximating those of biological neural networks that perform specific functions. The following are examples of three such architectures:

- In the center-surround architecture, neurons are arranged in one-layer sheets, and each neuron is connected to its immediate neighbors only (see figure). In nature, this architecture occurs most notably in the retina of the eye; it is also used to organize information coming from the ears and tactile sensors. In artificial neural networks, this architecture is most often found in those of the cellular-neural-network type. In both natural and artificial implementations, the basic functional topology is the same: the neural sheet is exposed to some input, and each neuron is prevented from firing by the inhibiting effects of approximately half of its neighbors.

One of the many phenomena detectable by use of the center-surround architecture is the location and movement of edges across receptive fields — for example, the edge of a shadow on a retina. The concept of edges could be generalized to include isotherms and isobars on an area spanned by a web of weather sensors and to enable the use of sensor webs to detect such phenomena as the spread of radiation or toxic chemicals, the spread of seismic activity, the spread of a traffic jam (in the case of a sensor web that spans a city), or the movement of an intruder against a background of starlight.



One Example of Center-Surround Architecture is that of a retinal neuron and its nearest neighbors. The balance between the stimulatory effect of light and the inhibitory inputs from the nearest neighbors is such that the central neuron is active only when the edge of the shadow crosses the central neuron sufficiently close to the center. In a field of center-surround neurons, only those along the edge of the shadow are active.

- The second architecture is that of autoassociative neural networks, which, in nature, enable organisms to recall old memories from partial or noisy stimuli. In an autoassociative network, each neuron is connected to every other neuron in the network. The excitability of any such neuron is determined by the state of all the other neurons and the strengths (weights) of the interconnections between neurons. For any state, the pattern of activation at the next instant in time is completely determined by the preset weights. The number of different firing patterns is 2^n, where n is the number of neurons in the net; because this number is finite, as the sequence of firing patterns proceeds, cycles are inevitable. Cycles that consist of repeated instances of the same pattern are called fixed points, and these fixed points can be chosen by setting the weights to make the points attract nearby patterns. The fixed points represent memories. An autoassociative sensor web could be used to search for known gaseous, biological, or geological signatures, for example.
- The third architecture is that of hypernetworks, which are groups of neural networks that can cooperate on vaguely defined tasks. Hypernetworks occur naturally in bee and ant colonies, schools of fish, and flocks of birds. For example, in a flock of birds, each bird functions, basically, as a single neuron connected only to its nearest neighbors. Each bird simply matches the speed and direction of nearest neighbors and keeps itself an equal distance between them. The entire flock seems to move as a single organism.

Swarms of neural networks could accomplish tasks that would be impossible for a single large neural network. For example, a swarm could spread out to cover a large area or move in single file to go through a small opening. Swarms of flying sensor pods, organized with simple hyperneural rules similar to those of flocks of birds, could perform a wide variety of exploratory and data-collection tasks.

This work was done by Charles Hand of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*

NPO-30317

System Locates Buried Objects Marked by Electromagnetic Tags

Marked objects can be located quickly and easily.

Lyndon B. Johnson Space Center, Houston, Texas

A relatively inexpensive, lightweight, durable, easy-to-operate radio-frequency (RF) instrument has been developed, along with special electromagnetic tags, for use in detecting buried objects to which the tags are attached. Each tag comprises a dipole antenna (basically, two collinear straight wires) with a passive, electrically nonlinear load between them. By virtue of the nonlinearity of the load, the antenna reradiates harmonics and/or mixer product(s) of one or more RF signal(s) transmitted by the instrument. The instrument detects one or more of the harmonics and/or mixer products and executes a time-of-arrival measurement procedure to locate the tag. The instrument is especially well suited for locating buried pipelines marked with such tags.

The instrument is expected to make it possible to overcome deficiencies in the means used heretofore to locate buried objects. These means have included various electromagnetic objects, tracer wires, acoustic detection, holography, ground-probing radar, and record-keeping.

- Inaccurate making and keeping of records are the bane of the natural-gas industry. Because landmarks can disappear and human errors occur, records are often imprecise.
- Prior electromagnetic and magnetic metal detectors can detect only objects that are metallic, large enough, and buried at depths of <3 ft (<0.9 m); and even when detection is achieved, it is difficult to know when the detector is positioned directly over an object.
- Tracer wires, which enhance the detectability of nonmetallic objects, must be carefully handled to protect them from corrosion and disintegration over the years.
- Active and passive acoustic detection techniques are promising but can be complicated by soil moisture and a variety of soil types. If a target is close, active acoustic imaging and acoustic holography are also inaccurate.
- Ground-probing radar (GPR), the most recent addition to the buried-object-location arsenal, has afforded limited success, in situations in which moisture is low and homogeneity is high. Moreover, GPR units must be operated by only trained, experienced professionals. For these reasons, GPRs frequently do not satisfy the needs of the natural-gas industry.

The design of the present instrument and of the associated antennas and loads for marking buried objects involves, among other things, the choice of transmitting and receiving radio frequencies to obtain efficient matches for a variety of burial depths and types and conditions of soil. In the case of a pipeline, a typical antenna is about 1.5 ft (≈0.5 m) long and the nonlinear load at the middle of the antenna has a volume of <1 cm³. In order to establish a location field, tags are set at intervals that range between 50 and 100 ft (between 15 and 30 m) or whatever other distance is most suitable in a given application.

The instrument, which is carried above the ground, includes one or more transmitters operating at a frequency or frequencies in the range from 10 to 100 MHz. The frequency or frequencies are chosen low enough to enable penetration of a wide range of soil types and high enough to enable the use of a conveniently short transmitting antenna or antennas. The harmonic and/or mixer-product frequency or frequencies to be monitored are chosen low enough that sufficient reradiated signal power reaches a receiver that is part of the instrument.

In one example, a 50-MHz transmitter with a power of 1 W would suffice for detecting pipelines buried as deep as 4 ft (1.2 m). In this case, the receiver could monitor the 100-MHz (second harmonic) reradiated signal with the help of band-pass filters and a diplexer that would suppress any second-harmonic signal component radiated by the transmitter. Provided that the location of a buried object is initially known or guessed to within a few meters (so that the instrument can be brought close enough to obtain a detectable reradiated signal), the instrument configured as described above could locate a buried marker to within a few centimeters.

This work was done by G. D. Arndt of ***Johnson Space Center*** *and J. R. Carl of Lockheed Martin.*

This invention has been patented by NASA (U.S. Patent No. 6,097,189). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center, (281) 483-0837. Refer to MSC-22743.

Advanced Capacitive-Sensor Turbine-Blade-Monitoring System

This system provides data on vibrations of blades and the shaft.

John H. Glenn Research Center, Cleveland, Ohio

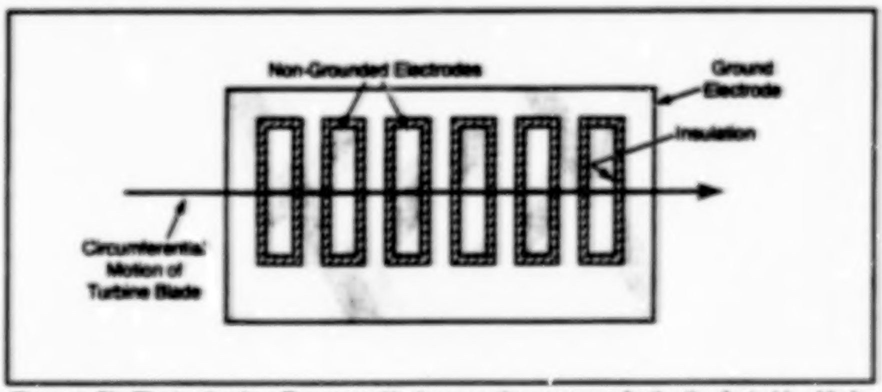


Figure 1. Six Electrodes in a Row capacitively sense the passage of a the tip of a turbine blade.

An electronic system that includes a capacitive proximity sensor is under development as a prototype of instrumentation systems for real-time monitoring of vibrations of turbine blades and shafts. Because vibrations are caused by stresses that can induce fatigue and/or are sometimes associated with damage, monitoring of vibrations can provide information needed to detect damage, detect incipient fatigue failures, and alter turbine operating parameters to prevent or postpone failures. The design of this system overcomes the frequency-response and spatial-resolution limitations

of prior capacitive-sensor-based turbine-monitoring systems. Its resolution is comparable to that of optical-sensor-based turbine-monitoring systems used in testing turbines at temperatures below their operating temperatures; however, unlike optical sensors, capacitive sensors can withstand high turbine operating temperatures [in some cases, >2,000 °F (>1,100 °C)].

The capacitive proximity sensor in this system (see Figure 1) includes N (N = 6 in the figure) stripe electrodes insulated from, and placed within recesses in, a larger ground electrode. In a fully developed version, the electrode surfaces would be flush with each other and the sensor would be mounted in a turbine so that the electrode surfaces would be flush with the surface of the rub strip: hence, in a fully developed version, the electrode surfaces would be curved at the radius of the rub strip. The sensors are excited with a DC bias between 100 and 200 V. Each of the non-grounded electrodes could be connected to individual signal processing circuits as in prior turbine-monitoring systems; instead, in this system, all of the non-grounded electrodes are electrically connected together and the resulting composite signal is applied to a single wide-band preamplifier. Hence, the sensing and preamplification portions of this system are simpler than those of prior systems.

The circumferential distance between adjacent non-grounded electrodes and the total circumferential extent of the electrode array are less than the circumferential distance between adjacent turbine blades. Consequently, a single blade passes completely by all the electrodes before the next blade arrives, and the output of the preamplifier is a burst of N pulses corresponding to the passage of the blade by each of the N non-grounded electrodes (see Figure 2).

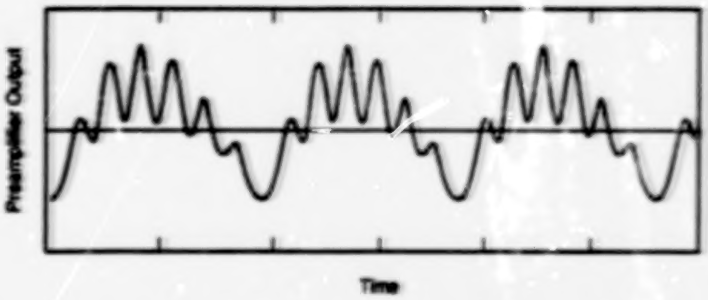


Figure 2. This **Preamplifier Output** contains three six-pulse bursts, indicating the passage of three turbine blades by a six-electrode sensor like that of Figure 1. The periodic variation in the pulse height within each burst is a spurious effect attributable, in this case, to the fact that the sensor was flat instead of curved to the radius of the rub strip.

The output signal of the preamplifier is digitized and then processed to measure the heights of the pulses and the times of arrival of the pulses in the burst. The height of each pulse is a direct measure of the distance between the blade tip and the sensor surface. The differences among intervals between times of arrival are measures of high-frequency vibration that manifests itself as circumferential oscillation at the blade tip. The intervals between subsequent bursts are taken as measures of the times of arrival of adjacent blades.

The design of the preamplifier is such as to suppress much of the noise at frequencies below the blade-passage frequency. This low-frequency noise is attributable to vibrations of sensor cables and other spurious phenomena. To reduce low-frequency noise further, in digital signal processing, a signal generated by fitting a curve to the preamplifier output when no blade is present is subtracted from the preamplifier output when blades are present.

This work was done by Wayne C. Haase of Aerogage Corp. and Michael J. Drumm of ExSell Inc. for **Glenn Research Center**. *For further information, please contact Dr. George Y. Baaklini at (216) 433-6016 or baaklini@grc.nasa.gov or see TSP's [page 1].*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17180.

System Mimics an Avionic Multiplexer/Demultiplexer

This virtual machine emulates an avionic computer and is used in a flight simulator.

Lyndon B. Johnson Space Center, Houston, Texas

The multiplexer/demultiplexer (MDM) emulator is the first virtual machine that can emulate an avionic computer. New flight software can be easily "dropped in," increasing operational flexibility. The MDM makes it possible to perform integration more quickly, reducing the need for additional hardware. The MDM emulator will be used extensively in the Space Station Training Facility (SSTF), where teams of astronauts and ground controllers will be trained in operation and utilization of the station — the first use of virtual-machine techniques for training of this type. In addition to being a major advance in virtual machines, the MDM emulator is economical: Although the cost of its hardware is estimated at $4 M (an estimate, as of year 2001, that includes the cost of development and testing), it has been estimated that the MDM emulator will save $12 M in labor costs.

The MDM emulator includes a '486 portable-computer-compatible virtual memory emulator board as its processor. This board can transfer data at rate large enough and with a latency small enough for running a simulator in real time. The simulator, in turn, makes it possible to load MDMs, personal computer systems, and robotic workstations in orbit. The MDM simulator is very flexible in that computers of all other types can also be functionally simulated.

The MDM emulator software is equally flexible. It consists of a boot subsystem, a kernel subsystem, and a device-simulation subsystem. The boot subsystem includes a self-test component and has sufficient "intelligence" to begin communicating with a host computer so that the rest of the software can be loaded. The kernel contains an executive component, a message component, and virtual-machine-setup and protection trap-handling routines. Device-simulating capabilities include the capability to (1) model missing hardware, (2) handle interfaces to the host computer and to devices outside the '486 card, and (3) use the message component to communicate with host-computer models of firmware controllers, sensors, and actuators.

The applicability of the MDM emulator is limited to avionic computers based on processors with hardware support for virtual memory addressing, memory protection

and paging, trapping input/output instructions, and rings. However, this limitation of applicability is not really a significant weakness in the software. Rather, inasmuch as the art of avionics is moving toward the use of high-performance commercial microprocessors, there will probably be a greater need for the virtual-machine techniques implemented by the MDM emulator in the future. Moreover, the MDM emulator lends itself well to a simulator like that of the SSTF because it enables the virtually seamless marriage of the simulator with flight computers. The MDM emulator gives a simulator access deeper within a flight computer. One of the biggest problems with integrating flight computers into simulators has been making the flight computers stop and start on demand. The MDM emulator satisfies this requirement.

This work was done by Robert Horton, Wayne Crawford, Larry Backus, Cary Cheatham, and Dwight Allbritten of Hughes Electronics Corp. for **Johnson Space Center.**

Title to this invention has been waived under the provisions of the National Aeronautics and Space Act [42 U.S.C. 2457(f)], to Hughes Electronics Corp. Inquiries concerning licenses for its commercial development should be addressed to

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P.O. Box 80028
Los Angeles, CA 90080-0028

Refer to MSC-22752, volume and number of this NASA Tech Briefs *issue, and the page number.*

FPGA-Based Test Bench for Nonvolatile Electronic Memories

Multiple chips can be tested simultaneously at relatively low cost.

NASA's Jet Propulsion Laboratory, Pasadena, California

A test bench based on field-programmable gate arrays (FPGAs) has been developed to reduce the cost of testing nonvolatile memory circuits. Specifications for endurance testing of memories can require test times as long as weeks — often impractically long in the case of commercial memory testers, which are expensive. The present FPGA-based test bench not only costs less than commercial memory testers do but can also be configured with multiple FPGAs to enable the simultaneous testing of many more memory chips than can be tested simultaneously on a commercial memory tester.

In comparison with the design of a commercial memory tester, the design of this test bench is more application-specific: The test bench is designed to perform certain reliability and endurance (life-cycle) tests on certain ferroelectric random-access memory (FRAM) and electrically erasable, programmable read-only memory (EEPROM) chips. The application-specific nature of the design offers advantages of lower cost, less complexity, and greater suitability for endurance testing. There is one disadvantage: Whereas a commercial memory tester can perform tests on many different types of memory chips without recoding, the FPGA-based test bench must be recoded for different kinds of chips.

The test bench was developed by use of a commercial prototyping board and a commercial 10,000-gate FPGA. At present, the test bench can be configured to operate as either of two testers. The first tester performs a reliability test that detects address-decoder faults and stuck-at faults and that cycles through all of the addresses in a memory. The second tester performs an endurance test, in which it writes to, and reads back from, the same address repeatedly. The second tester can perform endurance tests faster than can a commercial memory tester, especially in cases of memory circuits that are slow by modern standards.

When an error is detected in a test, the data logged includes the error number, the address where the error occurred, the cycle number (where one cycle is defined as one read-and-write operation to a single address), the incorrect data value read, and (in the case of the reliability test) the portion of the test in which the error occurred. The error data can be logged by one of two methods. In the first method, which is applicable if the tester is connected to the parallel port of a personal computer, a small program written for this purpose sends the data to the computer screen and saves the data in a file. The second method, which is still undergoing development, would enable the tester to be totally independent of a personal computer. In this second method, the FPGA bit stream would be written into an EEPROM, which would be used to configure the FPGA on power-up. Instead of using a personal computer to log the error data, a light-emitting-diode display would be used to read out the error data when a switch was flipped. The display would also indicate whether testing was taking place, and whether an error had occurred.

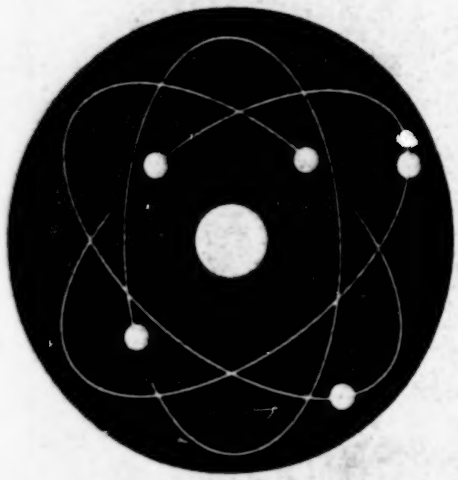
This work was done by Jagdishbhai Patel, Jeffrey Namkung, and Vikram Rao of Caltech for **NASA's Jet Propulsion Laboratory.** *Further information is contained in a TSP [see page 1].*
NPO-30374

Books and Reports

Deep-Space Ranging Using Pseudonoise Codes

A report discusses aspects of a ranging system in which the distance between the Earth and a spacecraft is determined from the difference between the phases of (1) modulation on a radio signal transmitted to the spacecraft and (2) a replica of the modulation transmitted back to Earth by a transponder on the spacecraft, received at Earth a round-trip-light-time after the original transmission. The system correlates the transmitted and return modulation for different phase shifts. The phase shift for which the correlation is maximum is deemed to be related to the round-trip signal-propagation time and, hence, to the distance. The modulations used in prior such systems were sequential square-wave tones or repeating pseudonoise tones, but not both in the same system. A proposed improvement would equip a ranging system to use either square-wave or pseudonoise tones. The report presents mathematical analyses and comparisons of the performances of square-wave and pseudonoise ranging. It is shown that in comparison with the existing system using sequential square-wave tones, a system using a set of pseudonoise codes would perform better (in terms of integration time and variance in distance) and could be configured and operated more easily.

This work was done by Jeff Berner and Scott Bryant of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "Operations Comparison of Deep Space Ranging Types: Sequential Tone vs. Pseudo-Noise," see TSP's [page 1].*
NPO-30387



Physical Sciences

Hardware, Techniques, and Processes

17 Correlation Spectrometers for Detecting Fires in Aircraft
18 Advanced Hardware and Software for Monitoring Contamination
19 Synthesis of Optical Pulses Using Brillouin Amplification
20 Multiple-Beam System for Fast Raman Spectrometry
20 Profile Refractometry for Measuring the Soret Effect
21 Fiber-Optic Liquid-Level Sensors

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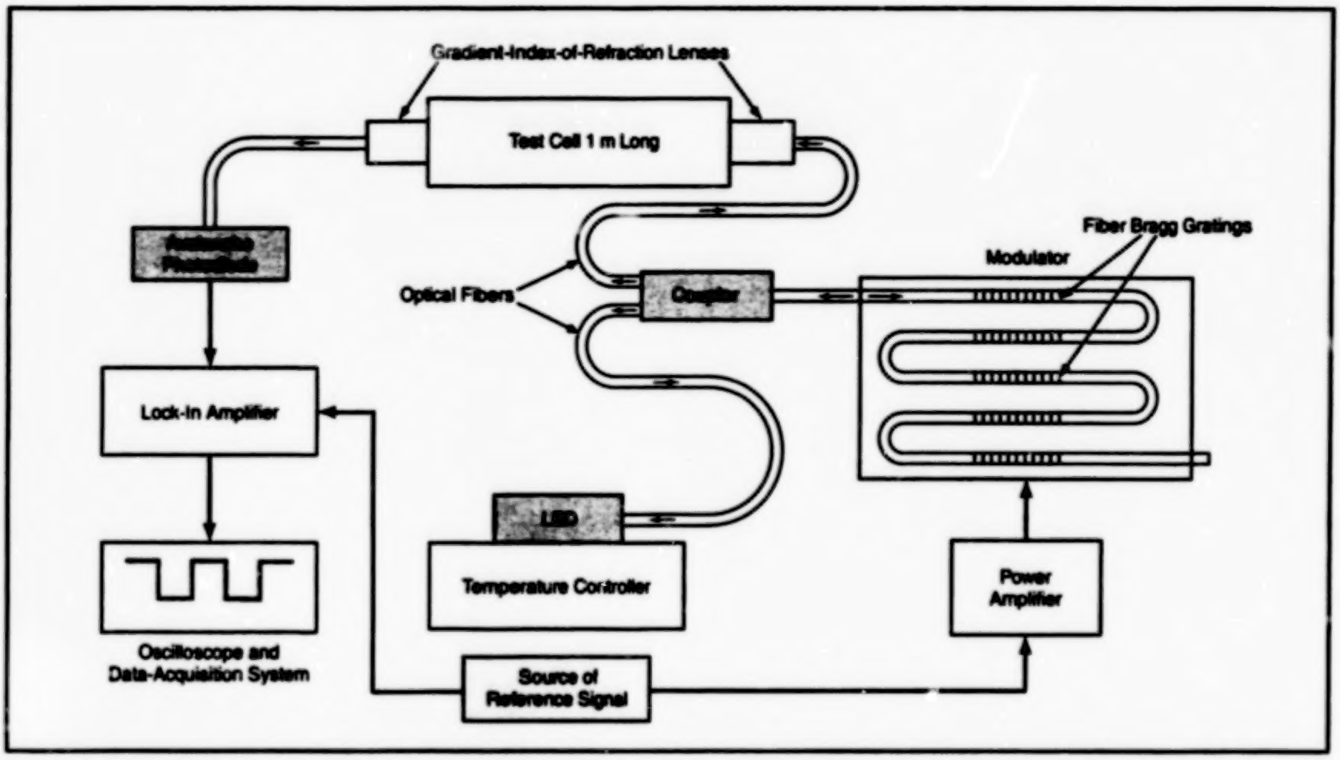
Correlation Spectrometers for Detecting Fires in Aircraft

Products of early stages of combustion would be detected with sensitivity and selectivity.

John H. Glenn Research Center, Cleveland, Ohio



Fiber Bragg Gratings Are Stretched Periodically to modulate the wavelengths of light reflected from them. The wavelength-modulated light is sent through a test cell, where the light is used for correlation spectroscopy to measure the concentration of a gas (in this case, HCl).

Compact, lightweight, sensitive correlation spectrometers for detecting gaseous byproducts of the onset of fire are under development. These spectrometers would be installed in aircraft, where early detection of fire could enable crews to respond with timely fire-suppression actions. Correlation spectroscopy involves measurements of absorption spectra of chemical species of interest but is not the same as classic absorption spectroscopy, which has been used for decades for detecting airborne chemicals. Classic absorption spectroscopy involves steady-state techniques that are not suited for rapid detection of compounds of immediate interest that may be present along with other compounds that are not of immediate interest.

In classical absorption spectroscopy, one measures the spectrum of light transmitted through an atmospheric region or a gas cell that is suspected of containing a compound of interest (hereafter denoted the target compound). The absorption spectrum is then computed from the transmission spectrum. In correlation spectroscopy, one uses a photodetector to measure the amount of light transmitted while illuminating the atmospheric region or sample cell by use of a phase- or wavelength-modulated, narrow-band optical source, the steady-state or nominal wavelengths of which coincide with known absorption spectral lines of the target compound.

The modulation causes the spectral lines of the illumination to move periodically into and out of registry with the absorbance bands of the target compound. The modulation appears in the output of the photodetector, with an amplitude related to the concentration of the target compound. The modulation in the photodetector output is measured with the help of a lock-in amplifier. Because the manifold of absorption spectral lines for each compound is unique and the use of phase or wavelength modulation in conjunction with a lock-in amplifier offers high sensitivity, correlation spectroscopy makes it possible to detect trace amounts of target compounds while discriminating against other compounds that might also be present in complex gas mixtures. Hence, correlation spectroscopy is well suited for detecting compounds typical of the early stages of fire while preventing the triggering of false alarms by other compounds.

The figure depicts a laboratory apparatus used to demonstrate the feasibility of a correlation spectrometer for detecting hydrogen chloride, which is one of the gases most commonly emitted at the onset of burning of paneling materials in typical aircraft. (Carbon dioxide, which is a product of complete combustion, is not useful for the sensitive detection of the onset of fire.) The source of light was a light-emitting diode (LED) with an emission spectrum spanning the wavelength band from 1,200 to 1,400 nm and a peak at about 1,300 nm. The light from the LED was coupled into an optical-fiber spectral reflector comprising four fiber Bragg gratings spliced in series. A fiber Bragg grating is an optical fiber, the index of refraction of the core of which is perturbed with a longitudinal spatial period chosen to obtain reflection at a desired wavelength. In this case, the spatial periods of the fiber Bragg gratings were chosen to obtain reflection peaks at wavelengths near 1,220 nm — wavelengths slightly less than those of a set of HCl absorption lines.

Light reflected from the fiber Bragg gratings was coupled into a test cell containing either atmospheric-pressure air or an atmospheric-pressure mixture of air with 500 parts per million (ppm) of HCl. After passing through the cell, the light was detected by use of an avalanche photodiode. The output of the photodiode was sent through a transimpedance

amplifier and a lock-in amplifier to a data-acquisition system. The reference (synchronizing) signal for the lock-in amplifier was the same one used to drive a power amplifier to effect wavelength modulation as described below.

The fiber Bragg gratings were mechanically clamped to an electromechanical stretcher, which was used to stretch the gratings in order to increase the wavelengths of their reflection peaks, thereby effecting wavelength modulation. The output of the power amplifier was used to drive an electromagnet that actuated the stretcher. The frequency of the reference signal, and thus of the modulation, was 60 Hz. In operation, this apparatus was found to provide indication of the concentration of the HCl gas in the cell, with a signal-to-noise ratio of 350 at 500 ppm. Further development efforts are expected to yield increases in sensitivity.

This work was done by Kisholoy Goswami of Intelligent Optical Systems, Inc., for **Glenn Research Center**.

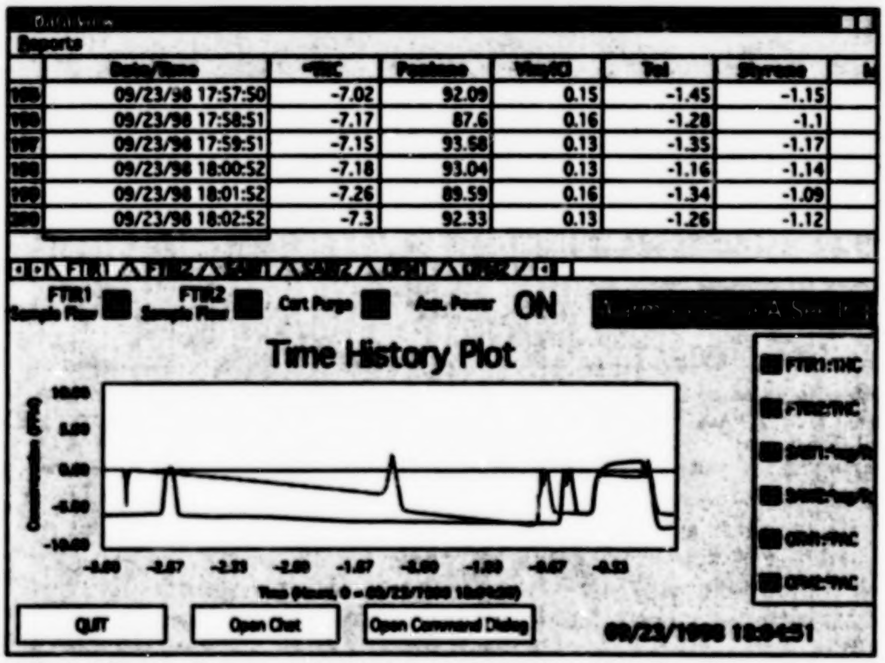
Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16897.

Advanced Hardware and Software for Monitoring Contamination

Sensor readings can be viewed both locally and remotely.

John F. Kennedy Space Center, Florida

An instrumentation system measures the concentrations of three principal contaminants (nonvolatile residue, hydrocarbon vapor, and particle fallout) in real time. The system includes a computer running special-purpose application software that makes it possible to connect the system into a network (which can, in turn, be connected to the Internet) to enable both local and remote display and analysis of its readings. The system was developed for use in a Kennedy Space Center facility that was required to be maintained at a specified high degree of cleanliness for processing a spacecraft payload that was highly sensitive to contamination. The system is also adaptable to monitoring contamination in other facilities and is an example of an emerging generation of sophisticated instrumentation systems that communicate data with other equipment.



A Typical Display of sensor readings includes textual and graphical information on the recent history of concentrations of selected contaminants.

The system includes a total of six sensors attached to a purged cart. There are two sensors of each type, for measuring the three principal contaminants at two different locations. The sensors for determining the concentrations of hydrocarbon vapors are Fourier-transform infrared (FTIR) spectrometers that measure the absorbance spectra of gases in internal gas cells in the wavelength range of 2.5 to 25 µm. The sensors for determining the concentrations of nonvolatile residues are surface-acoustic-wave devices, the resonance frequencies of which depend upon the amounts of material deposited on them. The sensors for monitoring particle fallout are small scatterometers.

The sensor readings (see figure) are digitized and time-stamped and the resulting data made available over a serial link from the cart to a computer workstation located elsewhere in the facility. The sensor readings are also displayed on a screen on the cart. The data can also be made available over the network to any computer equipped with special-purpose client software and with a Transmission Control Protocol/Internet Protocol (TCP/IP) connection; the computer can be located anywhere in the world. The data are packetized according to a special application-level protocol. Access to the data can be limited to authorized IP addresses, and, in any event, is limited by the need for the special-purpose client software to implement the application-level protocol.

The control of the system and the designation of IP addresses authorized to receive data are effected at the aforementioned computer workstation. From this location, control personnel can turn the nonvolatile-residue and particle-fallout sensors on and off, and re-zero and diagnose the FTIR spectrometers. They can monitor individual infrared spectra and can download them for off-line analysis. Other individuals monitoring the data via the network can provide typed comments to each other and to the control personnel via an the Internet-like chat utility.

To facilitate the development of the special-purpose software to effect the functions described above, there was first developed a set of software elements that enables the easy and rapid development and deployment of data-presentation application programs, not only for this system, but for a wide variety of systems that utilize a variety of data-communication mechanisms. The set includes a series of forms (objects), written in Microsoft Visual Basic, that follows a defined protocol. The set also includes similar objects written in Visual C++. The C

objects are suitable for use in code developed on embedded software systems, while the Visual Basic objects are better suited for use in software based on graphical user interfaces.

All of these objects utilize the same application-layer protocol, making it possible for messages to go back and forth within an application program, between different application programs on the same computer, and between application programs on separate computers, which can be connected via either a serial link or a network. The special-purpose software of the present instrumentation system includes a set of such objects that perform the communication functions.

The set of objects comprises the following three subsets:

- For assembly and transport of packets, including mediation of access by users, there are a serial-communication object, a network User Datagram Protocol (UDP) communication object, and a network TCP communication object.
- For routing of packets of data within an application program, there is a dispatcher object.
- For taking actions specified by messages, there is a do-action interface, which can be built into any object to make it aware of messages.

The communication objects, as well as any message-generating objects, notify the dispatcher objects of their messages. The dispatcher objects route messages to designated recipient objects, for action by the recipient objects. Because the protocol is consistent, intercommunication is simplified and uniform, making the application programs more scalable and flexible than they otherwise would be. The disposition of messages can even be dynamically modified to adapt to changing requirements.

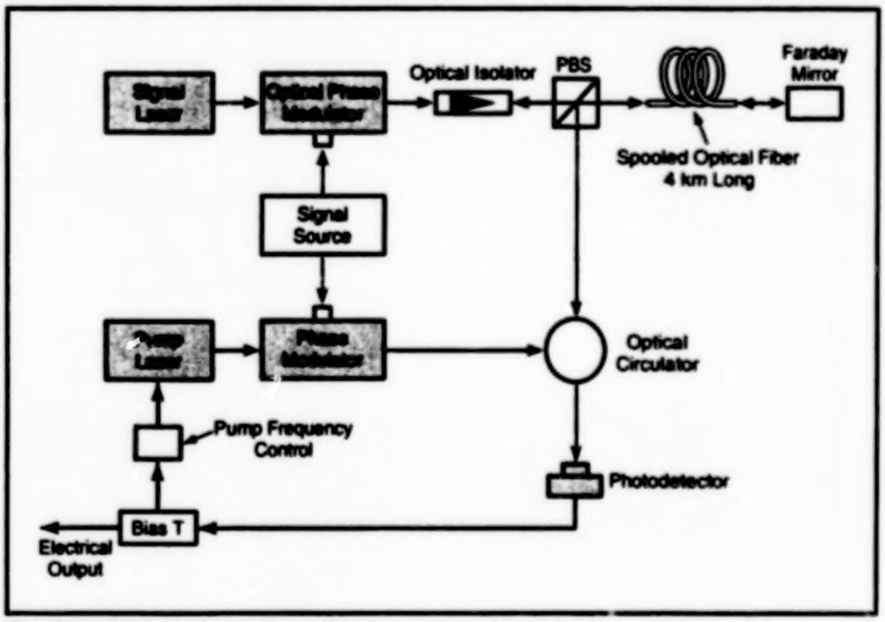
This work was done by Paul A. Mogan of **Kennedy Space Center** *and Christian J. Schwindt, Steven J. Klinko, Timothy R. Hodge, Carl B. Mattson, Paul Yocom, and K. Robert McLaughlin of Dynacs Engineering Co. Further information is contained in a TSP [see page 1].*

Synthesis of Optical Pulses Using Brillouin Amplification

Low-jitter pulses can be generated with controllable shape, duration, and repetition frequency.

NASA's Jet Propulsion Laboratory, Pasadena, California

A technique for Fourier synthesis of optical pulses involves radio-frequency (RF) phase modulation of laser beams, Brillouin selective amplification of modulation sidebands, and, finally, generation of pulses through coherent superposition of (and thus interference among) the sidebands. (Brillouin amplification is a consequence of a nonlinear interaction of the pump and signal beams with an optical fiber via the electrostrictive effect, and has been described in several prior articles in *NASA Tech Briefs*.) Coherent superposition is possible because the Brillouin selective sideband amplification (BSSA) automatically locks the various sidebands together in phase. The shape and duration of the pulses can be controlled by controlling the gain for each sideband, while the pulse-repetition frequency can be controlled by controlling the frequency of the modulation. Other attractive features of this technique include built-in optical amplification, simple electronic control, insensitivity to polarization, and conversion of a low-phase noise RF signal into low-jitter optical pulses.



This **Optoelectronic Apparatus** synthesizes optical pulses through superposition of phase-locked, Brillouin-amplified modulation sidebands of a laser beam.

One apparatus that has been used to demonstrate the technique (see figure) includes two diode-pumped yttrium aluminum garnet (YAG) lasers, denoted the "signal" and "pump" lasers, that operate at wavelengths ≈1,319 nm. The output beams from both lasers are phase-modulated by the same continuous-wave signal at a suitable RF (e.g., 7.7 GHz) that equals the desired frequency of repetition of optical pulses. The modulated signal beam is coupled, via a polarizing beam splitter (PBS), into a 4-km-long single-mode optical fiber on a spool. The polarization axis of the signal beam is made to coincide with the transmission polarization axis of the PBS.

At the far end of the long optical fiber, the signal beam is reflected by a 90° Faraday mirror, so that the polarization axis of the reflected signal beam is orthogonal to that of the forward-going signal beam everywhere along the fiber. Consequently, the reflected signal beam is further reflected, by the PBS, toward an optical circulator, from whence it is coupled into a photodetector.

The modulated pump beam is directed via the optical circulator to the PBS. The polarization axis of the pump beam is made parallel to the reflection polarization axis of the PBS, so that the pump beam is also made to travel along the long optical fiber. Like the signal beam, the pump beam is reflected at the far end by the 90° Faraday mirror so that the reflected pump beam is orthogonal to the forward-going pump beam everywhere along the fiber. Finally, the pump beam passes through the PBS toward the signal laser and is suppressed by an optical isolator before it reaches the signal laser. It is important that the forward-going pump beam always has the same

polarization as that of the backward-going signal beam; this condition is optimum for Brillouin amplification everywhere along the fiber and it eliminates polarization sensitivity of the Brillouin-amplification process.

The carrier frequency of the pump laser is adjusted so that the frequency of its peak Brillouin gain coincides with the +2 modulation sideband of the signal beam. Because both the signal and pump beams are modulated by the same RF signal, other Brillouin gain peaks generated by the corresponding modulation sidebands of the pump beam are automatically aligned with the corresponding modulation sidebands of the signal beam.

The apparatus includes a simple circuit that prevents relative frequency drift between the signal and the pump lasers. The circuit is based on the fact that when the signal sidebands are optimally amplified, the DC output of the photodetector attains a maximum value. The DC output of the photodetector can be extracted via a bias T and used to control the frequency of the pump laser.

This work was done by X. Steve Yao of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

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Refer to NPO-20870, volume and number of this NASA Tech Briefs *issue, and the page number.*

Multiple-Beam System for Fast Raman Spectrometry

A complete vibrational spectrum can be obtained from one laser pulse.

John H. Glenn Research Center, Cleveland, Ohio

A developmental instrumentation system rapidly acquires full Raman spectra of gas molecules. The system is based on the principle of multiplex coherent antistokes Raman spectroscopy (CARS) and incorporates improvements over prior multiplex CARS systems. Among the potential applications for systems like this one are (1) imaging (including microscopy), (2) detection of molecular species of interest for diagnosis of flames and other possibly rapidly changing systems, and (3) detection of molecular species of interest for gas chromatography.

Heretofore, multiplex CARS systems have been capable of obtaining Raman spectra rapidly (as fast as one spectrum per laser pulse). The spectra in question are associated with vibrations of the molecules of interest. The bandwidths of the dye lasers that provide the excitation in such systems have typically been limited, such that in a typical case, the measured spectral range covers no more than about one-third of the vibrational wavelength range of the molecular species of interest. This developmental system is capable of covering the full vibrational wavelength ranges of typical molecules of interest.

The developmental system includes a neodymium: yttrium aluminum garnet (Nd:YAG) pump laser, a hydrogen Raman cell, a degenerate β-barium borate optical parametric oscillator (BBO OPO), associated optics for manipulating multiple beams of light so that the beams overlap, detection optics, a monochromator, and an intensified charge-coupled device. In operation, a broadband beam and a narrowband beam are overlapped in space and time at a sampling point. The multiplex CARS process, based upon the nonlinear optical effect, generates a new broadband beam that is blue-shifted with respect to the narrowband beam. This new beam is dispersed and detected by use of the monochromator and the intensified charge-coupled device. For each pulse of the pump laser, a complete vibrational spectrum can be recorded.

In a test, the system was used to detect various molecular species at different positions in a sooty flame. By observing the heights of the peaks in the vibrational spectra as the sampling point was moved outward from the center of the flame, it was possible to determine that the concentration of C_2 decreased while that of CO_2 increased.

This work was done by Peter C. Chen's research group at Spelman College for **Glenn Research Center**. *Further information is contained in a TSP [see page 1].*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17194.

Profile Refractometry for Measuring the Soret Effect

Spatially and temporally resolved data are acquired across the span of a fluid.

Marshall Space Flight Center, Alabama

Profile refractometry is a laser-based technique for measuring the index of refraction of a fluid as a function of time and position in a fluid. The technique was developed for use in quantifying the Soret effect in a binary fluid subject to an applied thermal gradient. (The Soret effect is the mass diffusion of chemical species due to an imposed thermal gradient.) More precisely, profile refractometry enables measurement of both dynamic and steady-state local gradients in the index of refraction of the fluid. These gradients are related in a known way to gradients in the composition of the fluid and thus to the Soret coefficient.

Profile refractometry overcomes some of the weaknesses of a steady-state beam-deflection (SSBD) technique used heretofore to obtain index-of-refraction data for calculating the Soret coefficient. In the SSBD technique, one transmits a laser beam parallel to a thermal gradient in a fluid contained in a narrow gap. The SSBD technique yields only a single measure that is averaged over the applied temperature range. The SSBD technique does not yield spatially resolved data, and is limited to a very small applied thermal gradient because a large thermal gradient would refract the laser beam by more than the few milliradians allowed by the narrow gap geometry.

In profile refractometry, a wide laser beam with an initially planar wavefront is

made to propagate along an axis perpendicular to a thermal gradient in a bulk fluid. Unlike in SSBD, the beam samples a cross section of the fluid, yielding spatially resolved index-of-refraction data for all positions of interest along the thermal gradient. There is no need to keep refraction angles small and thus no need to limit the applied thermal gradient because the laser beam is not obscured at any refraction angle. In addition, because profile refractometry samples bulk fluid, the spurious refraction caused by capillary action, surface tension, and edge effects is less than that in a fluid sampled within a narrow gap as in the SSBD technique.

The image formed by the refracted laser beam contains information on the continuous refraction profile over the entire span of the fluid. When corrected for thermal effects, this profile represents a continuous measure of the concentration gradient in the fluid at every point along the axis between the thermal boundaries.

When a thermal gradient is applied to a fluid, the Soret effect (if it occurs in that fluid) gives rise to a transient fluid phase in which molecular migration occurs. Under some conditions, there develops a steady-state fluid structure that contains a stable concentration gradient. Methods of analysis that take these effects into account, and software that implements these methods, have been developed to process refraction-profile data to obtain values for each of the terms that define the Soret coefficient. The end result of the Soret analysis performed by the software is a three-dimensional matrix that contains data on the Soret coefficient as a function of time, position in the fluid, and temperature. Depending on the experimental conditions, convection and dynamic effects may also be represented in the data.

This work was done by Larry W. Mason of Lockheed Martin for **Marshall Space Flight Center**. *For further information, contact the company at (303) 971-9067.*
MFS-31567

Fiber-Optic Liquid-Level Sensors

Liquid-level-measuring systems based on fiber optics are under development as compact, lightweight alternatives to systems based on float gauges and other conventional sensors. For liquids that pose explosion hazards, fiber-optic sensors are inherently safer because they do not include electrical connections inside tanks. Fiber-optic sensors can be designed in many different forms to exploit reflection and transmission of light to measure liquid levels. Most of them are based on the effects of the indices of refraction of liquids on the waveguide properties of optical fibers: In a typical case, there is a loss of internal reflection of guided electromagnetic modes as a result of contact between the outer surface of optical fiber and a liquid. Hence, a substantial decrease in the light transmitted from one end of the fiber to the other is taken to indicate that liquid has come into contact with a suitably designed probe at the end of the fiber. A system capable of determining the level of liquid to within a known increment of depth could be constructed by placing the probes of a number of such sensors at known increments of depth in a tank.

This work was done by Syed H. Murshid of Florida Institute of Technology for **Kennedy Space Center**. *For further information, please contact:*

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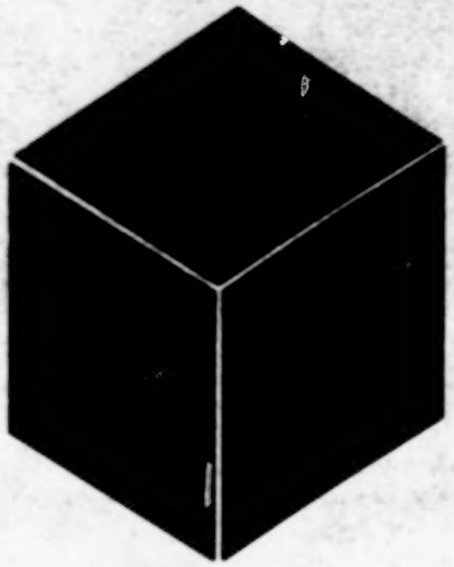


Materials

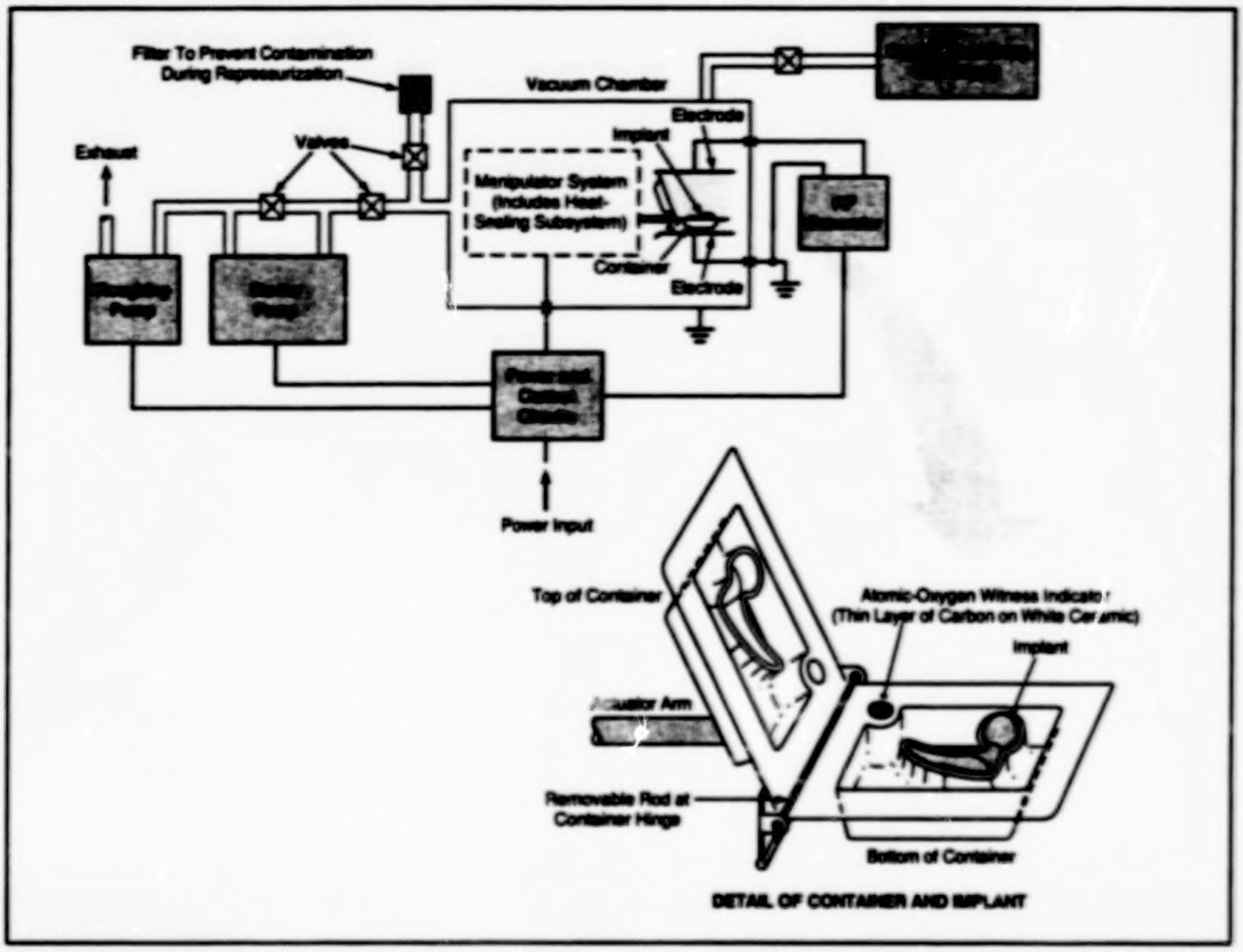
Hardware, Techniques, and Processes

25 Removing Bioactive Contaminants by Use of Atomic Oxygen
26 Flexible Piezoelectric Actuators

Removing Bioactive Contaminants by Use of Atomic Oxygen

Bioactive contaminants are removed without using liquid chemical baths or high temperatures.

John H. Glenn Research Center, Cleveland, Ohio



An Orthopedic Implant Is Decontaminated by exposure to monatomic oxygen from a radio-frequency plasma. The manipulator system positions the implant and container so that both the implant and the container surfaces adjacent to it are decontaminated, and seals the implant in the container once decontamination is complete.

A method of removing endotoxins and other biologically active organic compounds from the surfaces of solid objects is based on exposure of the objects to monatomic oxygen generated in oxygen plasmas. The monatomic oxygen reacts strongly and preferentially with the organic contaminants to form volatile chemical species. The method was developed especially for removing such contaminants as lipopolysaccharides, proteins, lipids, and other biologically active contaminants from surfaces of orthopedic implants prior to sterilization and implantation; if not removed, these contaminants can contribute to inflammation that sometimes necessitates the surgical removal of the implants.

A major advantage of this method is that unlike in prior methods of decontaminating implants, there is no need to expose the implants to strong liquid chemical baths or high temperatures, both of which can degrade implant materials. Moreover, whereas the prior methods do not ensure complete removal of the contaminants, the present method ensures complete removal of the contaminants from all surfaces that receive sufficient exposure to monatomic oxygen.

The apparatus used to implement this method includes a vacuum chamber, a radio-frequency (RF) generator connected to electrodes in the chamber for generating a plasma, and a manipulator system (see figure). Included in the manipulator system are a special thermoplastic container for positioning one or more implant(s) or other object(s) for exposure to monatomic oxygen from the plasma, an actuator arm for manipulating the container, and a subsystem for heat-sealing the implant(s) or other object(s) in the container after treatment.

At the beginning of a typical operational sequence, an implant to be decontaminated is placed in the special container and the container is positioned in the vacuum chamber to expose both the top surface of the implant and the inner surface of the top of the container to the plasma. The chamber is evacuated, then backfilled with air, oxygen, or a gaseous mixture that includes oxygen, at a pressure between 0.1 and 300 millitorr (between 0.013 and 40 Pa). The RF power is turned on to generate a plasma in the backfill gas. Volatile species formed by oxidation of contaminants become dispersed in the vacuum chamber and are simply removed by the vacuum-chamber pump system.

After the top surface of the implant and the inner surface of the top of the container have been exposed to the plasma long enough to ensure decontamination, the manipulator system which closes the container and prevents uncontrolled rolling of the implant, withdraws the container into a chute, flips the container upside-down, pushes the container back out of the chute, and reopens the container; as a result, the former bottom surface of the implant and the former bottom inside surface of the container are now on top and are exposed to the plasma, while the decontaminated former top surface of the implant is now on the bottom, resting on the decontaminated inside surface of the former top of the container.

After sufficient exposure to the plasma to ensure decontamination, the manipulator system again closes the container and withdraws it into the chute. Then the RF power is turned off, and the implant, with its container, is either vacuum sealed or the pumping system is turned off and ambient air, nitrogen, or inert gas is readmitted to the chamber through filters that prevent recontamination of the implant and container. The container with the implant inside is heat sealed by moving into the heat-sealing subsystem, where the top and bottom parts of the container are clamped at the perimeter and partially melted to seal the implant inside, where it is surrounded by, and in contact with, container surfaces that have been decontaminated. As thus packaged, the decontaminated implant can be stored, transported, and/or sterilized by exposure to gamma rays.

This work was done by Bruce A. Banks of **Glenn Research Center** *and Michael A. Banks and Eric B. Banks. Further information is contained in a TSP [see page 1].*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16871.

Flexible Piezoelectric Actuators

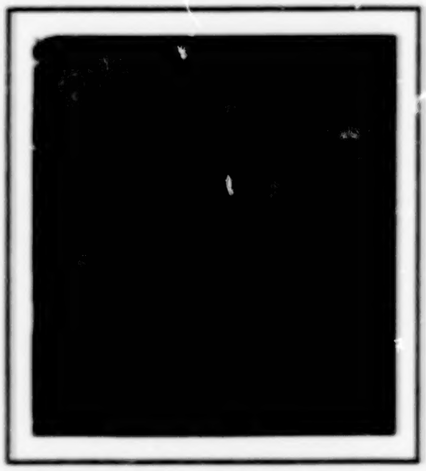
Actuators can be affixed to curved surfaces or embedded in composite structures.

Langley Research Center, Hampton, Virginia

Flexible, compact, hermetically sealed piezoceramic actuators with robust electrical leads have been developed for use in actively controlling aerostructures to suppress noise, vibration, and flutter on experimental aircraft. An actuator of this type, denoted a Flex Patch is meant to be placed in a strategic location to oppose a predominant mode of vibration in a given structure.

A Flex Patch is a composite structure that includes a lead zirconate titanate (PZT) wafer and nickel ribbon leads sandwiched between thermoplastic layers. During fabrication, the structure is held together with Kapton (or equivalent) polyimide tape and placed in an autoclave for processing through a prescribed temperature-and-pressure cycle.

The most remarkable attribute of a Flex Patch is its flexibility (see figure) and its ability to perform as well while bent as it does when undeformed. Taken by itself, the piezoceramic wafer that goes into a flex patch is extremely brittle and is broken when deformed even slightly. The flexibility of the Flex Patch greatly exceeds that of the piezoceramic wafer that it contains. The unique flexibility makes it possible to attach a Flex Patch to a highly curved surface. This characteristic also makes it possible to embed a Flex Patch into a composite-material structure of any of a variety of shapes.



A Flex Patch Is Very Flexible, even though it contains a piezoceramic wafer that, taken by itself, would be extremely brittle and could not be bent as much as shown here.

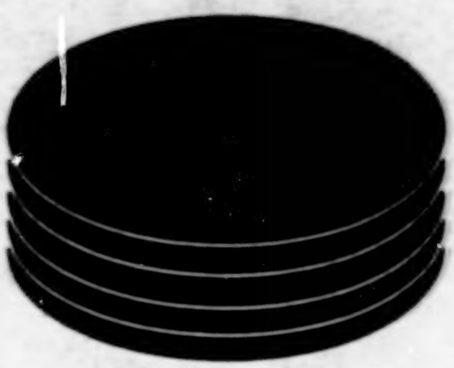
Another benefit of the Flex Patch is the strength of electrical-lead attachments, which have been sources of failure in the past because of the difficulties associated with the soldering of leads to a PZT. These leads stay connected firmly in place and form a monolith along with Flex Patch composite, providing an electrically insulated package. The leads and the PZT stay hermetically sealed — an advantage for use in adverse environments. Flat, flexible, male clincher connectors (similar to those found within computers) are crimped onto the ends of the ribbon leads to finish the package.

Thus far, Flex Patches have been operated at low voltages. After a Flex Patch has been subjected to a high-voltage poling process, the common operating potential is 200 V, although the Flex Patch could also function when connected to a standard 110-V, 60-Hz household outlet.

In addition to working well as an actuator, a Flex Patch can also generate an electrical response to a mechanical input. This characteristic makes it possible to use a Flex Patch as a sensor.

This work was done by Garnett Horner, John Teter, and Eugene Robbins of **Langley Research Center.**

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to Brian Beaton, Technology Commercialization Program Office, NASA Langley Research Center at (757) 864-7210 or e-mail at b.f.beaton@larc.nasa.gov. Refer to LAR-15908.



Computer Programs

Physical Sciences

29 Program Predicts Temperatures at Nodes of a Thermal Network

Mathematics and Information Sciences

29 Software for Turbo Decoding on Digital Signal Processors
29 Software for Automation of Real-Time Agents
29 Software for Allocation and Scheduling of DSN Resources
30 GUI Program for Planning Paths of Rovers
30 Software Disseminates Lessons Learned on a Large Project
30 Software Recognizes Similar Patterns of Different Sizes

Life Sciences

30 Software for Modeling Biochemical Reactions

28

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Physical Sciences

Program Predicts Temperatures at Nodes of a Thermal Network

Node Prediction for Thermal Networks (NOPTHER) is a computer program that predicts steady-state temperatures at unobserved nodes of a thermal network, given noisy values of the temperatures measured at observed nodes. The program is based partly on modeling of the heat fluxes among nodes as sums of external heat loads, conduction terms (products of conduction coefficients and differences among nodal temperatures), and radiation terms (products of radiation coefficients and differences among the fourth powers of nodal temperatures). The temperature-prediction problem is formulated as an optimization problem — more specifically as a nonlinear least-squares minimization problem with a single quadratic constraint imposed by the measured temperatures. The problem is solved by the method of Lagrange multipliers. NOPTHER incorporates algorithms that find local minima of a cost functional through Newton iteration. What distinguishes these algorithms from other such algorithms is that they exploit specific characteristics of the temperature-prediction problem that enable the use of a fast and memory-efficient computational method. The algorithms have been shown to be at least an order of magnitude faster than are prior algorithms used for the same purpose.

This program was written by Mark Milman and Mitiadis Papalexandris of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-30173.

Mathematics and Information Sciences

Software for Turbo Decoding on Digital Signal Processors

Software for decoding turbo codes that have been adopted as standard by the Consultative Committee for Space Data Systems is being developed along with hardware built around integrated-circuit digital signal processors (DSPs) that execute the software. The software enables reliable communication at data rates up to 700 kb/s at a signal-to-noise ratio (SNR) of −0.2 dB if a rate-1/6 code is used, or at an SNR of 0.8 dB if a rate-1/3 code is used. The software is written primarily in assembly language and runs on eight high-performance DSPs in parallel. Frames of data are distributed among six of the DSPs, which perform iterative decoding. A "stopping rule" is used to detect early convergence, thereby reducing the average number of iterations and, hence, increasing decoding speed. The remaining two DSPs perform ancillary functions, including frame synchronization, tracking of frame arrival times, de-randomization (sometimes used to ensure a bit-transition density sufficient for receiver tracking), and cyclic redundancy checking for verification of data.

This work was done by Kenneth Andrews; Valerie Stanton; Samuel Dolinar, Jr; Fabrizio Pollara; Jeff Berner; and Victor Chen of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-30249.

Software for Automation of Real-Time Agents

Closed Loop Execution and Recovery (CLEaR) is an artificial-intelligence computer program under development designed for automated command sequence generation, execution, monitoring, and recovery. As a component of the Deep Space Network's (DSN's) prototype Common Automation Engine (CAE), CLEaR relieves human operators of much of the burden of setting up, monitoring, and controlling a DSN communication station. CLEaR is also being adapted for automation of other real-time agents, such as robotic spacecraft, robotic land vehicles (rovers), and robotic aircraft. CLEaR enables a control computer at a DSN station to respond to a set of tracking goals by issuing commands to configure station hardware and software to provide requested communication services. CLEaR utilizes operational knowledge encoded into a textual declarative knowledge base to create command sequences, then executes the command sequences while monitoring their progress and dynamically modifying them on the basis of its operational knowledge when necessary. To generate a tracking plan (expressed as a control script) that satisfies the tracking goals, CLEaR utilizes an extended version of CASPER, which was described in "Software for Continuous Replanning During Execution" (NPO-20972) *NASA Tech Briefs*, Vol. 26, No. 4 (April 2002), page 67. Then CLEaR monitors the execution of the tracking plan and modifies the plan in response to changing requirements and/or unforeseen events.

This program was written by Forest Fisher, Barbara Engelhardt, Colette Wilklow, Steve Chien, Russell Knight, Gregg Rabideau, and Robert Sherwood of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-21040.

Software for Allocation and Scheduling of DSN Resources

The TMOD (Telecommunications and Mission Operations Directorate) Integrated Ground Resource Allocation and Scheduling (TIGRAS) computer program provides an integrated computing environment for analysis, allocation, and scheduling of antennas and other ground resources of NASA's Deep Space Network (DSN). TIGRAS includes sophisticated forecasting and schedule-generation algorithms that enable users to perform their tasks with the help of decision-support information. TIGRAS connects to a centralized database, both for retrieval of data needed to perform analyses and for storage of results of analyses. TIGRAS has a graphical user interface that combines time-line navigation, display selection, graphics, text, and metrics, all on one screen for viewing. Users can open multiple windows to display user requirements, viewperiods, forecasts, and schedules, all simultaneously. Users can also edit data while viewing them. Included in TIGRAS is software that controls access to selected parts of TIGRAS on the basis of privileges assigned to users. TIGRAS supports mission-phase-based analysis in addition to weekly analysis, so that users can focus more on planned mission-phase activities than on activities associated with

fixed time intervals. TIGRAS can be executed on personal computers that utilize the Windows 2000, Windows 95, or Windows NT operating system.

This program was written by Yeou-Fang Wang, Chester Borden, and Silvino Zendejas of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-30247.

GUI Program for Planning Paths of Rovers

The Path Planning Graphical User Interface is a computer program that, as its name indicates, generates a graphical user interface (GUI) for software that plans paths for robotic vehicles (rovers) to be used in exploration of remote planets. This GUI program is designed for use in conjunction with the A* Search Algorithm, which plans the path of a rover between starting and ending positions specified by the user. With the help of the GUI, the user can change rover positions interactively and can modify the parameters used by the path-planning search algorithm. Prior to the development of this GUI program, it was typical practice for engineers to hand-code path-planning algorithms in order to encode parameters particular to their application, so that testing with different parameters and terrain maps was tedious and costly. The present GUI program makes it easy for users to test their path-planning logic by downloading or modifying current terrain environments and search parameters, without need for a costly learning process.

This program was written by Ayanna Howard of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-30320.

Software Disseminates Lessons Learned on a Large Project

A computer program automates the process of collecting, storing, and disseminating information on lessons learned in a large, multidisciplinary project in which multiple organizations participate. Developed for the International Space Station project, the program could also be used on other projects to institutionalize successes and reduce the incidence of failures, thereby reducing costs, risks, and schedule times. The program provides a closed-loop reporting system that captures lessons learned, distributes them to affected organizations, and requires positive feedback to assure appropriate implementation by each organization across the project. The program includes a conventional database subprogram combined with a Web-based subprogram that helps to identify and document lessons learned, collects the relevant information about lessons learned, and automatically distributes the information to the affected parties via electronic mail. The program also requires, and simplifies the submission of, documents by the affected parties to ensure that the lessons are applied by the affected parties. Johnson Space Center has recently adopted the program as its centerwide lessons-learned program, and minor modifications and enhancements are underway.

This program was written by Nathan Vassberg of **Johnson Space Center**; *Don Erwin, Shama Kruse, Greg Nenninger, and Sue Nall Cochran of Barrios Technology; Glenn Jenkinson of Boeing International Space Station; and Leland Jackson and Paula Gentry of Science Applications International Corp. Further information is contained in a TSP [see page 1].*
MSC-23116

Software Recognizes Similar Patterns of Different Sizes

A computer program undergoing development detects patterns that may differ in size but are otherwise similar to a specified pattern. Conceived to enable the automated recognition of features in images of planets and asteroids acquired by exploratory spacecraft, the program can also be used for scale-invariant recognition of patterns in other applications. The program requires no advance knowledge or mathematical modeling of a pattern to be recognized; instead, the program trains itself on one or more examples of a pattern provided by the user. The program synthesizes virtual examples by resampling the user-provided example(s) at different pixel spacings. The result of the resampling is a set of continuously scalable detectors, which can be regarded as implementing an extension of matched filtering (also known as template matching in the computer-vision and pattern-recognition literature), which was developed in the early 1940's for radar and communication applications. The program has shown promise in tests on images of terrain of several astronomical bodies. For example, in the case of images of bowl-floored Lunar craters wider than 4 pixels, the program exhibited an 80-percent probability of detection and a 12-percent false-alarm rate.

This program was written by Michael C. Burl and Timothy Stough of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-30269.

Life Sciences

Software for Modeling Biochemical Reactions

Cellerator is a computer program that automatically generates and solves differential equations for complex sets of chemical reactions like those in living cells. Cellerator provides a mathematical and computational infrastructure for characterizing reaction pathways and the interactions between complex molecules (e.g., proteins and nucleic acids) and cellular environments. The user effectively defines the pathways by specifying an input set of chemical reactions. Examples include enzymatic reactions, creation and degradation of various chemical species, binding and unbinding reactions, phosphorylation reactions, and transcription and translation of nucleic acids. More complex signals, such as a chemical cascade, can also be specified. Cellerator translates the specifications of chemical reactions into the corresponding set of differential equations, then solves these equations numerically. Cellerator provides an explicit description of output at several steps through the model-generation process; this feature affords flexibility by facilitating intervention by the user to modify the computational model "on the go," as might be desirable, for example, to correct errors.

This program was written by Bruce Shapiro, Eric Mjolsness, and Andre Levchenko of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-21122.

Mechanics

Hardware, Techniques, and Processes

33 Mechanisms for Reliable One-Time Deployment of Panels
34 Electroactive-Polymer Actuators With Selectable Deformations

Books and Reports

35 Sonic-Boom Tests of Model of a Supersonic Business Jet Plane
36 Optimization of Synthetic Jet Actuators

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Mechanisms for Reliable One-Time Deployment of Panels

These mechanisms overcome the disadvantages of both pyrotechnic and thermal release mechanisms.

Goddard Space Flight Center, Greenbelt, Maryland

Mechanisms denoted restraint/release/deployment-initiation (RRDI) devices have been invented to enable the rapid, reliable, one-time deployment of panels that have been hinged together and stowed compactly by folding them together at the hinges. Although the RRDI devices were originally intended for use in deploying the solar photovoltaic panels that generate electric power for a spacecraft, they are also suitable for deploying other, similarly hinged panel arrays (including solar photovoltaic panels) in terrestrial applications. The RRDI devices overcome the disadvantages (shock and the consequent potential for damage) of explosive release devices as well as the disadvantages (slowness and high power demand) of electrically actuated thermal release devices.

Figure 1 depicts an array of panels in the stowed and deployed states in the original spacecraft application. During stowage, the RRDI devices clamp the panels together, at their hinged edges, against brackets attached to the main body of the spacecraft. At the time of deployment, the RRDI devices cease to clamp the panels. The hinges are typically of a strain-energy type: they carry little load during stowage, but when the clamping forces are removed, they spring open from the folded condition to assist in deploying the panels.

Figure 2 presents an exploded view of an RRDI device. During stowage, the panels are stacked and clamped between the upper bracket and a base. The edge of each panel at the clamping location is fitted with a U-shaped bracket. Serrations on the U-shaped bracket of each panel mate with the serrations on the U-shaped bracket of the adjacent panel, base, or upper bracket; these serrations serve to keep the panels from shifting from their desired stowage position as long as they remain clamped.

The clamping force (compressive preload) applied by each RRDI device is applied by torquing the adjustment bolt. The outermost panel (see upper bracket) is held in place by a separation bolt,

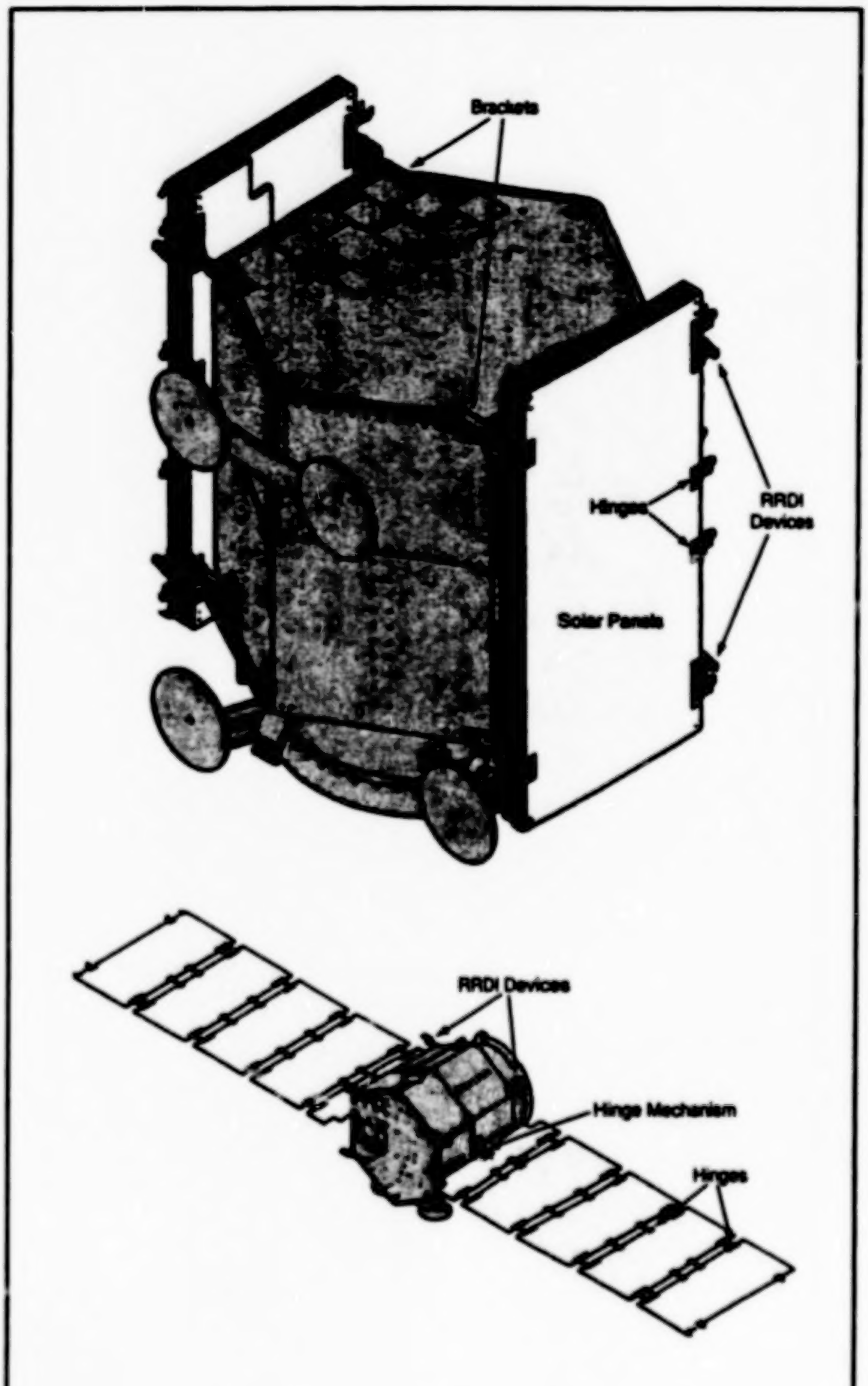


Figure 1. Solar Panels Are Deployed from compact stowage by unfolding them at hinged edges.

which is secured (preloaded) in the separation-nut assembly. The separation-nut assembly is a commercially available nonexplosive electromechanical device. At the time of deployment, the separation-nut assemblies of all the

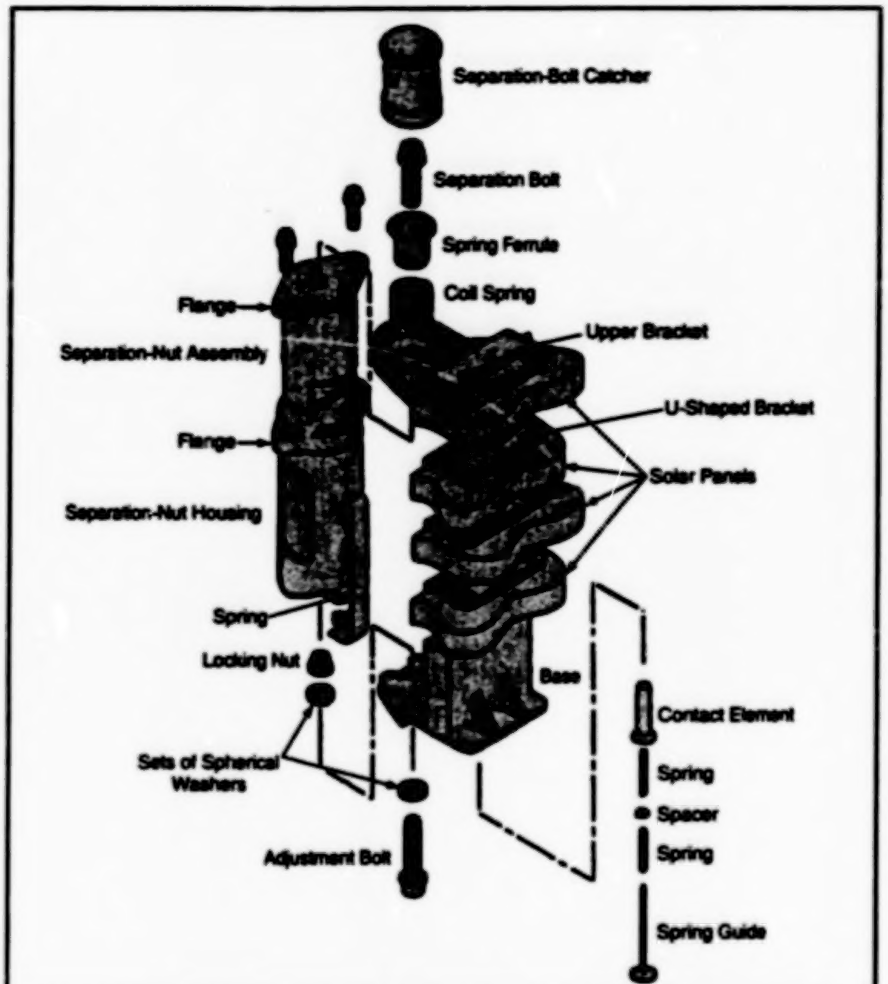


Figure 2. An **RRDI Device** is a nonexplosive electromechanically actuated, quick-release clamp that includes springs for preloading and for reliable deployment of the panels of Figure 1.

RRDI devices are electrically energized to make them release their separation bolts. Once the separation bolt has been released, strain energy accelerates the bolt into the bolt catcher, and the spring ferrule and coil spring assist in quickly withdrawing the separation bolt from the separation-nut housing. The spring ferrule and coil spring further insure that the separation bolt remains in the bolt catcher. The bolt catcher is basically a closed-end cylinder that contains a small piece of crushable material inside to absorb the kinetic energy of the bolt. A spring-loaded contact element (within the base) protrudes through the base and pushes the panels outward for positive deployment. A long leaf spring located on the side of the separation-nut housing acts as a bumper and guides the panel stack-up during deployment.

This work was done by Michael T. Izumi of TRW, Inc., for **Goddard Space Flight Center**. *Further information is contained in a TSP [see page 1].*

This invention has been patented by NASA (U.S. Patent No. 5,810,296). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Goddard Space Flight Center [see page 1]. Refer to GSC-13931.

Electroactive-Polymer Actuators With Selectable Deformations

There are numerous options for selecting materials, configurations, and modes of operation.

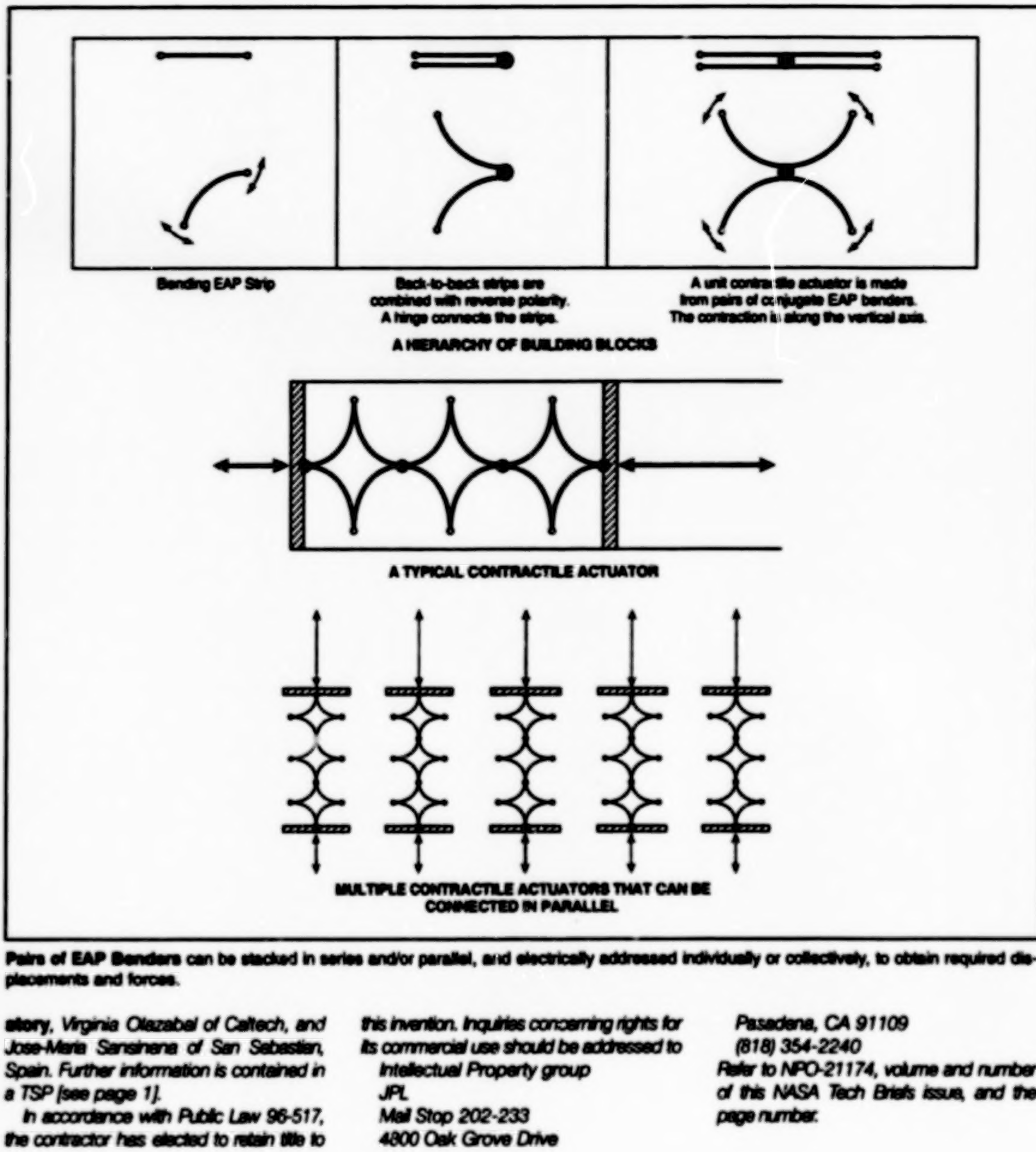
NASA's Jet Propulsion Laboratory, Pasadena, California

Efforts are underway to develop compact, lightweight electromechanical actuators based on electroactive polymers (EAPs). An actuator of this type is denoted an electroactive-polymer actuator with selectable deformation (EAPAS). The basic building blocks of these actuators are sandwichlike composite-material strips, containing EAP layers plus electrode layers, that bend when electric potentials are applied to the electrodes. Prior *NASA Tech Briefs* articles that have described such building blocks as parts of actuators for specific purposes include "Robot Hands With Electroactive-Polymer Fingers" (NPO-20103), October 1998; "Robot Arm Actuated by Electroactive Polymers" (NPO-20393), June 1999; "Wipers Based on Electroactive Polymeric Actuators" (NPO-20371), February 1999; and "Miniature Electroactive-Polymer Rakes" (NPO-20613), October 2001.

The EAPAS concept admits of almost endless variations in the selection of materials, actuator configurations, and modes of operation; it must suffice here to present only a few illustrative examples. EAPs that can be used in EAPASs include electronically conductive, ion-exchange, ferroelectric, and electrostrictive polymers; graft elastomers; ferrogels; and possibly others. An EAPAS can comprise one or more pair(s) of bender strips placed back-to-back and stacked in a parallel, serial, or parallel/serial arrangement (see figure), as needed to satisfy force and displacement requirements for a given task. The following are a few examples of options for design and operation:

- The pairs of benders in a given EAPAS can be electrically addressed individually, all together, or in intermediate combinations to control the displacement and/or shape of the EAPAS.
- Stacked benders can be enclosed in a protective case, effectively rendering an EAPAS a compact linear motor.
- EAPASs can be embedded in deformable "smart" structures for controlling their shapes.
- An EAPAS designed mainly as a contractile actuator (in other words, a puller) could serve as an artificial muscle: for this purpose, it would be anchored at one end and would pull on a wire (which would serve as an artificial tendon) at the other end.
- A more complex EAPAS could serve as a tactile display device.

This work was done by Yoseph Bar-Cohen of **NASA's Jet Propulsion Labor-**



Pairs of EAP Benders can be stacked in series and/or parallel, and electrically addressed individually or collectively, to obtain required displacements and forces.

story, *Virginia Olazabal of Caltech, and Jose-Maria Sansinena of San Sebastian, Spain. Further information is contained in a TSP [see page 1].*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

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Refer to NPO-21174, volume and number of this NASA Tech Briefs issue, and the page number.

Books and Reports

Sonic-Boom Tests of Model of a Supersonic Business Jet Plane

A report discusses wind-tunnel tests of a scale model of a conceptual two-engine jet airplane designed to carry 10 passengers, have a range of 4,000 miles (≈6,400 km), cruise at a mach number of 2.0, and generate a low sonic boom [characterized by a shock overpressure of ≤ 0.5 lb/ft^2 (≤24 Pa)]. The model could optionally include either of two differently sized nacelle submodels representing alternative engine designs. In each test, the pressure was measured at intervals along a horizontal line at a specified height below the model. One conclusion drawn from predicted and measured pressure values is that it is more difficult to tailor the geometry of this airplane for low sonic boom than it is to do so for a larger supersonic airplane capable of carrying 300 passengers and for which

the allowable shock overpressure is 1.0 lb/ft^2 (48 Pa). It was found that decreasing the allowable overpressure intensifies the conflicts between the design choices for reducing sonic boom and those for increasing aerodynamic efficiency. It was also found that due to the nacelles' aft location, their contribution to the shock overpressures could be expected to be small enough to be unnoticeable by an observer on the ground.

This work was done by Robert J. Mack of **Langley Research Center**. *To obtain a copy of the report, "An Analysis of Measured Sonic-Boom Pressure Signatures From A Langley Wind-Tunnel Model of A Supersonic-Cruise Business Jet Concept," see TSP's [page 1].*
LAR-16277

Optimization of Synthetic Jet Actuators

A report presents a study oriented toward optimization of synthetic jet actuators. [A synthetic jet actuator is a fluidic control device that partly resembles a loudspeaker. It typically comprises a piezoelectric actuator/diaphragm situated in a cavity, facing an orifice or nozzle at the opposite end of the cavity.] The instant report describes an experimental synthetic jet actuator equipped for tuning through variation of some of its cavity dimensions and its excitation frequency and for selection of either (1) clamping of the edge of the diaphragm between flat surfaces or (2) pinning of the edge of the diaphragm between steel O rings. The report goes on to discuss the effects of the cavity and nozzle geometry, diaphragm design, excitation frequency, and other design features on the vibrational resonance of the diaphragm, the acoustic resonance of the cavity, the coupling (or lack thereof) of these resonances, and the overall performance as characterized by the displacement at the center of the diaphragm or the speed of the jet at a specified distance from the orifice. Conclusions reached in this study are that (1) the pinning configuration results in better performance than does the clamping configuration and (2) the maximum performance is achieved by matching the resonant frequencies of the diaphragm and the cavity.

This work was done by Fang-Jenq Chen of **Langley Research Center**. *To obtain a copy of the report, "The Optimized Synthetic Jet Actuators," see TSP's [page 1].*
LAR-16234

Machinery

Hardware, Techniques, and Processes

39 Apparatus for Friction Stir Welding of Pipes

39 Automated System for Fluid and Electrical Connections

Apparatus for Friction Stir Welding of Pipes

FSW heads would move circumferentially and pipes would be supported against FSW loads.

Marshall Space Flight Center, Alabama

A proposed apparatus would effect friction stir welding (FSW) along a circumferential path to join two pipes. The apparatus is denoted an "orbital FSW system" because the circumferential motion of the FSW head would be similar to the motions of welding heads in commercial orbital fusion welding systems.

Unlike fusion welding, FSW involves large forces between the welding head and the workpieces. It is necessary to react these forces to prevent the workpieces from moving. Moreover, when the workpieces are pipes, they must be supported from within to prevent them from collapsing or undergoing undesired changes in shape when FSW forces are applied. The proposed system would provide the required motions of the FSW head plus the necessary support and reaction forces.

In FSW, a shouldered pin tool is plunged into the workpieces up to its shoulder with a controlled tilt and is rotated while being pushed or moved along the weld joint. The workpiece material under the tool becomes frictionally heated to plasticity, stirred, and pushed into place as the tool moves along, leaving behind the welded joint.

The proposed apparatus would include a FSW head with a retractable pin tool that would be actuated electrically, hydraulically, or pneumatically. The FSW head would be mounted diametrically opposite an external reactive roller on an external rotating assembly that would include circumferential driven gears in engagement with driving gears actuated by a motor. A roller assembly fixed to the sections of pipe to be joined would keep the external rotating assembly concentric with the pipes while allowing this assembly to rotate.

The apparatus would include internal reactive rollers located on the same diametral line as that of the FSW head and the external reactive roller. The internal reactive rollers would be driven to rotate along with the external rotating assembly in order to maintain this alignment. Thus, the internal reactive rollers would always be positioned to react the diametral FSW load and thereby prevent distortion of the pipes.

The apparatus could also be used to FSW solid rods, in which case the internal reactive rollers would not be needed or used. As described thus far, the apparatus would be used for FSW of pipes and rods with circular cross sections. However, because the apparatus would be computer-controlled and fully adjustable, it might be applicable to some noncircular cross sections.

This work was done by R. Jeffrey Ding and Robert W. Carter of ***Marshall Space Flight Center.***

This invention has been patented by NASA (U.S. Patent No. 6,259,052). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to Sammy Nabors, MSFC Commercialization Assistance Lead, at (256) 544-5226 or sammy.nabors@msfc.nasa.gov. Refer to MFS-31269.

Automated System for Fluid and Electrical Connections

The Smart Umbilical Mating System (SUMS) is an automated, three-degree-of-freedom, scalable system for quickly mating, demating, and/or remating ganged umbilicals. SUMS connects electrical and fluid paths between spacecraft and ground support equipment whether liftoff or side mount for NON T-0 umbilicals. SUMS prevents electrical arcing and leakage of fluids by providing for automated alignment of mating connectors and verification of mating. SUMS could readily be adapted to such other applications as servicing of aircraft, orbiting spacecraft, or ground vehicles. Major elements of SUMS include mating cones equipped with force sensors with integral latches; computer control; robotic vision with tracking aided by laser beams; actuation by a compliant pneumatic motor; and a secondary mate plate, which holds the ground-side fluid electrical connectors in proper alignment, is pneumatically actuated to complete mating once the cones have been latched, and is the only part of the system that one must change to adapt SUMS to different applications. A commercial version plumbed with electrical power, communications, fuel, lubricants, and coolant fluids could be installed at a central location for servicing land vehicles. SUMS could be utilized between moving vehicles. Automated functions could include electronic identification of vehicles to prevent errors; recording of data about the vehicle; its consumption of fluids; sampling for wear analysis; maintenance scheduling; distance traveled; and topping off or changing of all fluids in the correct amounts.

This work was done by Ronald L. Remus, Arthur Roberts, Perry Hartford, and Chau Pham of Merritt Systems, Inc., for ***Kennedy Space Center.*** *Further information is contained in a TSP [see page 1].*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

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Refer to KSC-12138, volume and number of this NASA Tech Briefs issue, and the page number.

Fabrication Technology

Hardware, Techniques, and Processes

43 Lithographic Fabrication of Mesoscale Electromagnet Coils
43 Using Dry Ice as a Coolant for Cutting Tools
44 Automated Apparatus for Welding To Seal Pyrotechnic Devices

42

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Lithographic Fabrication of Mesoscale Electromagnet Coils

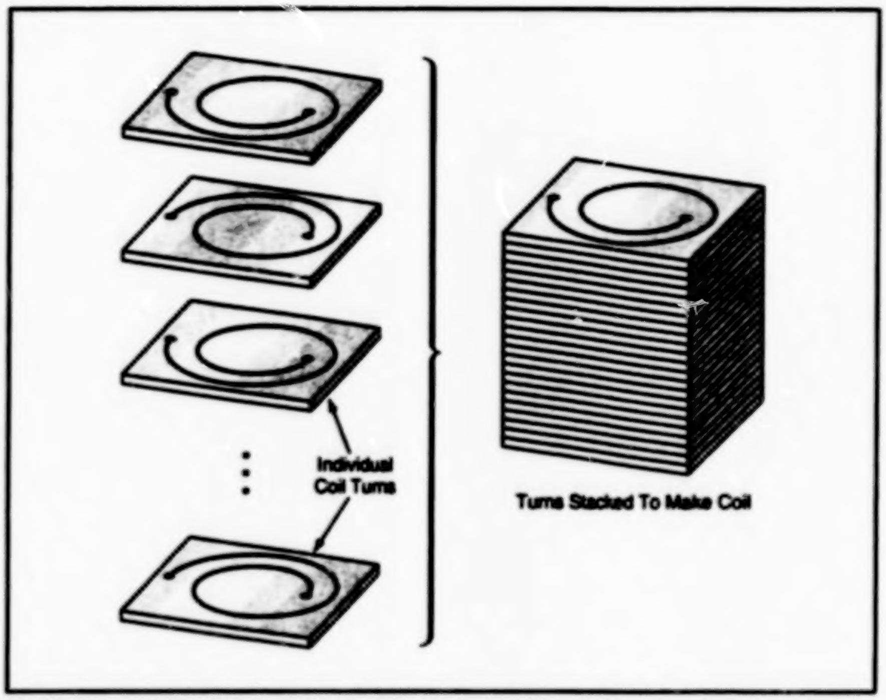
Fabrication should be faster and cheaper than in conventional winding.

NASA's Jet Propulsion Laboratory, Pasadena, California

A partly lithographic method of fabrication is being developed to enable the economical mass production of mesoscale electrically conductive coils for miniature electromagnets, solenoids, electric motors, and the like. This or a similar method is needed to overcome the limitations of prior techniques:

- The practical limit of fabricating miniature coils by conventional winding has been reached at a minimum wire width of ≈25 μm. At this limit, fabrication is a slow, expensive process that requires very skilled technicians.
- Current techniques of microfabrication (e.g., those used to make microelectromechanical devices and integrated circuits) are limited to coils of no more than about 25 turns. This number of turns is insufficient for many anticipated applications in which hundreds of turns would be needed to generate sufficient magnetic flux.

In the present developmental method, thick-film optical lithography is used to generate a series of spiral patterns, and copper is plated into the patterns, thereby forming individual turns of a coil. Then the turns are freed, stacked, and bonded together with the turns electrically connected in series (see figure). It should be possible to make coils of hundreds of turns in very small packages. It should also be possible to scale coils down to sizes smaller than those achievable by conventional winding. This method is compatible with batch fabrication and is expected to cost much less than does fabrication of the smallest conventionally wound coils.



Coil Turns are formed lithographically, then stacked and bonded together to make coils.

This work was done by Victor White, Juergen Mueller, and Dean Wiberg of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*

NPO-20966

Using Dry Ice as a Coolant for Cutting Tools

Unlike conventional liquid coolants, dry ice would not introduce contamination.

Lyndon B. Johnson Space Center, Houston, Texas

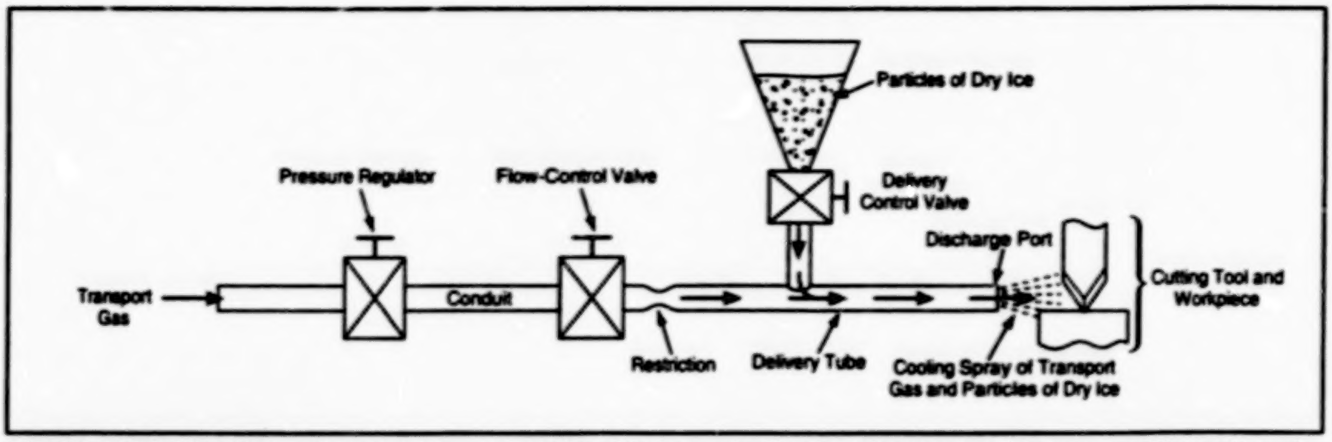
Particles of dry ice (frozen carbon dioxide) entrained in gas flows would be used during machining to cool cutting tools and workpieces, according to a proposal. Solid carbon dioxide particles that impinge on a tool and workpiece would absorb heat generated in the cutting process. The absorbed heat would cause the particles to vaporize. The consequent outflow of cold carbon dioxide gas would remove cutting debris and would provide additional cooling.

The cooling capacities of the liquid coolants used customarily in machining are marginal. Most such liquids are at least mildly hazardous and at least mildly corrosive or otherwise harmful to cutting machines, and they contaminate workpieces, making it necessary to clean workpieces after machining. Moreover, it is expensive to separate coolant liquids from machining debris for environmentally sound disposal.

In contrast, carbon dioxide is already present in the atmosphere and would not introduce any contamination. In addition, the vaporization of carbon dioxide is expected to remove heat more effectively, thereby extending the useful lives of cutting tools, increasing the accuracy of cutting, reducing and/or preventing damage to heat-sensitive materials to be cut, and/or making it possible to cut at higher speeds without degrading the cutting tools and/or the materials to be cut. Yet another advantage is that out-flowing carbon dioxide could help to prevent burning of workpiece materials (e.g., magnesium and titanium) that are susceptible to combustion when cut in air.

An apparatus for cooling by the proposed method could be constructed by (1) modifying an atomizer to handle particles of dry ice instead of a liquid and (2) adding insulation to limit the sublimation of the dry ice during storage and transit to the point of application. Referring to the figure, a supply of transport gas (e.g., air, carbon dioxide, or nitrogen) would be introduced at the inlet at sufficient pressure to provide adequate flow through the pressure regulator. Downstream from the regulator, the gas would flow through the flow-control valve, then would be throttled by the restriction before entering the delivery tube.

The hopper above the delivery tube would contain the supply of dry ice. The delivery-control valve would adjustably



A Slightly Modified Atomizer would generate a spray of particles of dry ice entrained in a flow of transport gas. The spray would be used to cool a cutting tool and workpiece.

throttle the flow of particles of dry ice into the delivery tube. The particles would become entrained in the flow of transport gas, and the resulting mixture of transport gas and dry-ice particles would flow to the discharge port, which would be positioned to deliver the flow to the cutting tool and the workpiece.

This work was done by Thomas A. Hall and Thomas O. Hall of **Johnson Space Center.**
MSC-22829

Automated Apparatus for Welding To Seal Pyrotechnic Devices

An automated, remotely controllable apparatus has been developed for resistance welding for hermetic sealing of pyrotechnic devices, as a substitute for special-purpose welding equipment that is no longer commercially available. Hermetic sealing of a pyrotechnic device involves a sequence of closely spaced, precise, spot welds made with low heat to minimize the potential of ignition. For safety, the welding must be performed under remote control. The apparatus includes a rotary table with a chuck, in which is mounted a fixture that holds the pyrotechnic device to be welded. The rotary table is programmed to step through appropriate angular increments (e.g., 360° in 1° increments). After each increment, a switch is closed to actuate a solenoid valve to extend a pneumatic cylinder to drive a welding head toward the pyrotechnic device. A spring-loaded electrode in the welding head is forced into contact with the pyrotechnic device with increasing force until a switch closes at a preset contact force, triggering a pulse of welding current through the welding electrode and workpiece with a return path through the welding fixture. The welding head is then retracted, the rotary table steps through the next increment, and the foregoing process is repeated.

This work was done by Todd J. Hinkel, Carl W. Hohmann, Richard J. Dean, Scott C. Hacker, and Douglas W. Harrington of **Johnson Space Center.** *Further information is contained in a TSP [see page 1].*
MSC-23139

Mathematics and Information Sciences

Hardware, Techniques, and Processes

47 Web Site Provides Enhanced Facility-Management Database
47 A Bit-Wise Adaptable Entropy Coding Technique

Books and Reports

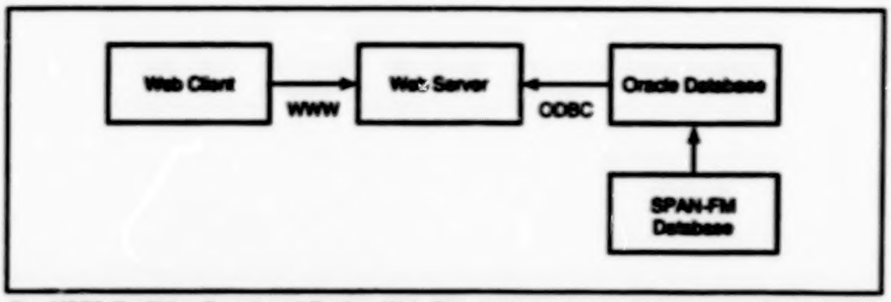
48 Software for Internet Collaboration on Mars Rover Operations

Web Site Provides Enhanced Facility-Management Database

Data needed for capital-investment decisions are made easily accessible for managers.

Marshall Space Flight Center, Alabama

The Marshall Space Flight Center (MSFC) Facilities Functional Review web site provides dynamic electronic publication of select portions of MSFC's facility-management database. This is a user-friendly site that provides a comprehensive view of all relevant facility and program information in a format that integrates plans, costs of operations, conditions of facilities, utilization of facilities, capabilities for research and development in each facility, research and development investments, capital investments, and organizational responsibilities. The site was developed to assist managers at all organizational levels in making decisions regarding capital investments and program plans.



The MSFC Facilities Functional Review Web Site, implemented by several computer hardware and software subsystems dynamically publishes a facility-management database.

The figure is a simplified schematic diagram of the major functional blocks of the web site and the relationship between the web site and a client. The software used to administer the site is a combination of World Wide Web (WWW)-based server software and computer-aided design (CAD)-based database-management software. The software and hardware components of the web site and the parts of the database to which they pertain are summarized as follows:

- The SPAN-FM software is used to manage data on property and space. These are stored in an Oracle database that resides on an Intergraph Pentium server computer running the Microsoft Windows NT Server operating system.
- The WWW server is another Intergraph Pentium computer running the Microsoft Windows NT Server operating system and version 4.0 of the Microsoft Internet Information Server (IIS) software, which is part of the NT4.0 Option Pack. This portion of the software has been configured for intranet only; that is, to restrict access to clients located at MSFC.
- The dynamic portions of the web site use the Microsoft Active Server Pages Scripting Engine (ASP) software for a Common Gateway Interface (CGI). (ASP is also a component of the NT 4.0 Option Pack.) All programs involved in delivering the dynamic content via the WWW are written in Visual Basic script and are implemented through this scripting engine. The scripts are processed on the server side and are delivered to clients in standard Hypertext Markup Language (HTML) so that any common browser software and operating system can be used to gain access the information on the site.
- Database connectivity between ASP and Oracle is achieved through Microsoft ODBC (Open Database Connectivity) software. The ODBC and Oracle drivers provide seamless access to the SPAN-FM data in Oracle from the web site.
- Facility floor plans are designed by using the Intergraph Corporation's Project Architect software to generate MicroStation (Bentley Systems) design files. These design files are packaged and viewed by use of Intergraph Corporation's Digital Print Room Software.

By means of this web site, capital investment and program plans are traceable to each facility and vice versa. The site saves time that would otherwise have to be spent investigating or searching for information needed to make decisions. The basic design of this web site could be adapted to aid managers of other large institutions who need rapid access to comprehensive information for making decisions of a capital-investment nature.

This work was done by James Wyckoff and Debra Hendon of ***Marshall Space Flight Center*** *and Donna Robinson and Brian Dial of Intergraph Corp. For further information, please contact Caroline Wang, MSFC Software Release Authority at* caroline.wang@msfc.nasa.gov.
MFS-31342

A Bit-Wise Adaptable Entropy Coding Technique

New data compression method offers efficient compression and fast decoding.

NASA's Jet Propulsion Laboratory, Pasadena, California

A recently invented coding technique for data compression is based on recursive interleaving of variable-to-variable-length binary source codes. The technique can be used as a key component in data compressors for a wide variety of data types, including image, video, audio, and text data.

The technique is adaptable in that the probability estimate used to encode a data bit can be updated with each new bit. This can result in better compression performance compared to encoders that require a fixed or slowly changing probability estimate.

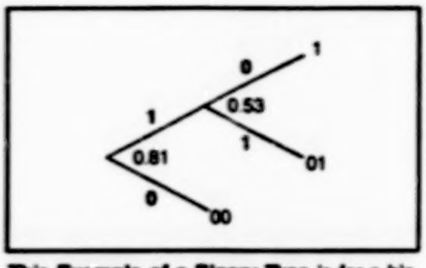
The technique seems to have advantages over the prior entropy coding method called arithmetic coding. The technique is particularly amenable to the design of relatively simple, fast decoders. Moreover, because the technique offers flexibility in the choice of parameters for a particular design, it is possible to trade compression performance versus speed. A straightforward code design procedure can be used to produce an encoder with compression efficiency arbitrarily close to the theoretical limit, with increasing complexity as the limit is approached.

The coding problem solved by this technique is that of compressing a sequence of source bits. The technique allows the estimated probability (p_i) that the ith source bit (b_i) is zero to depend on the values of the preceding source bits, correla-

tions or memory in the source, and any other information available to both the encoder and the decoder. The technique efficiently encodes the source sequence by recursively encoding groups of bits with similar probabilities, ordering the output in a way that is suited to the decoder.

Before encoding, input bits are inverted as needed to force $p_i \geq 1/2$. For the purpose of encoding, the probability range from 1/2 to 1 is partitioned into several narrow intervals. Associated with each interval is a bin that is used to store bits. When b_i arrives, it is placed in the bin that corresponds to the probability interval that contains p_i. Because each interval spans a small probability range, each bin can be regarded as corresponding to some nominal probability value. For each bin except the leftmost one (which contains probability 1/2), an exhaustive prefix-free set of binary code words is specified. When the bits collected in a bin form one of the code words, these bits are deleted from the bin and the value of the code word is encoded by placing one or more new bit(s) in other bins. (The bits in each bin are arranged in a specific order that make decoding possible.) Thus, bits arrive in various bins either directly from the source or as a result of processing code words in other bins. The net effect of this process is to cause bits to migrate to the leftmost (uncoded) bin, from whence they are transmitted.

The formation of code words is represented by a binary tree (see figure) for each bin except the leftmost one. Each code word is assigned a terminal node in the tree. Branch nodes of the tree are labeled to represent destination bins, and the branch labels (zeroes and ones) correspond to output bits that are placed in the bins.



This Example of a Binary Tree is for a bin with a nominal probability of 0.9 and for which the set of code words is {00, 01, 1}. Output bits arising from this bin are placed in bins with nominal probabilities of 0.81 and 0.53.

Once the end of the source bit sequence has been reached and no code words remain in any bin, there are still likely to be partially formed code words in one or more bins. Because these bits are needed for decoding, one or more extra bits are appended to each partial code word to form complete code words, which are then processed in the normal manner. The extra bits can be regarded as being used to "flush" the encoder.

In practice, the encoder and decoder do not track probability values. Instead, each bin is assigned an index, starting with 1 for the leftmost (uncoded) bin. The label for each node in the binary tree is the index (rather than the nominal probability value) of the bin to which the next output bit is mapped. There is imposed a requirement that each output bit from the tree for bin j must be mapped to a bin with index strictly less than j. No computations involving probability values are needed, apart form those that may be required to map each input bit to the bin of the appropriate index. (Although probability values are largely unneeded for the operation of an encoder and decoder, it is useful to track probability values to design a good encoder.)

If the trees and bins are well designed, then on the average, the number of bits used to describe a code word is less than the code word length, and data compression occurs. Some redundancy is present because the bins have positive width; in other words, the probability associated with a bit that arrives in a bin usually does not exactly equal the nominal probability for that bin, and bits in the leftmost bin are transmitted uncompressed, even though many do not have probability exactly equal to 1/2. However, by increasing the number of bins and/or the size of the trees, one can trade complexity for performance and decrease the maximum redundancy to arbitrarily small values.

Although the underlying compression process relies on binary encoding, any nonbinary source can be first converted to a binary one before encoding. Thus, the technique can be applied to nonbinary sources as well.

This work was done by Aaron Kiely and Matthew Klimesh of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*

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Refer to NPO-21101, volume and number of this NASA Tech Briefs *issue, and the page number.*

Books and Reports

Software for Internet Collaboration on Mars Rover Operations

A report provides additional information about two major subsystems of the software system described in "Software for Ground Operations for a Prototype Mars Rover" (NPO-21235), *NASA Tech Briefs*, November 2001. The software system was designed for, and field-tested on, the Field Integrated Design and Operations rover — a prototype similar to rovers of the planned 2003 Mars Explorer Rover mission. The software subsystems addressed in the report are the Web Interface for Telescience (WITS) and the Multi-mission Encrypted Communication System (MECS). The WITS (aspects of which have been described in several prior *NASA Tech Briefs* articles) displays information downlinked from the rover (principally, images from several rover cameras) along with alphanumeric data and annotations registered with terrain features. The MECS enables secure communication between a primary terrestrial operations center and geographically distributed, Internet-based users. The emphasis in the report is on the capability, afforded by the WITS and the MECS acting together, to enable geographically dispersed users to communicate with each other and to collaborate in the generation of a sequence of commands to be uplinked to the rover.

This work was done by Jeffrey Norris and Paul Backes of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*
NPO-21231

Life Sciences

Hardware, Techniques, and Processes

51 Laser-Induced Shock Waves Would Lyse Cells for Analysis

51 Improved Technique for Detecting Endospores via Luminescence

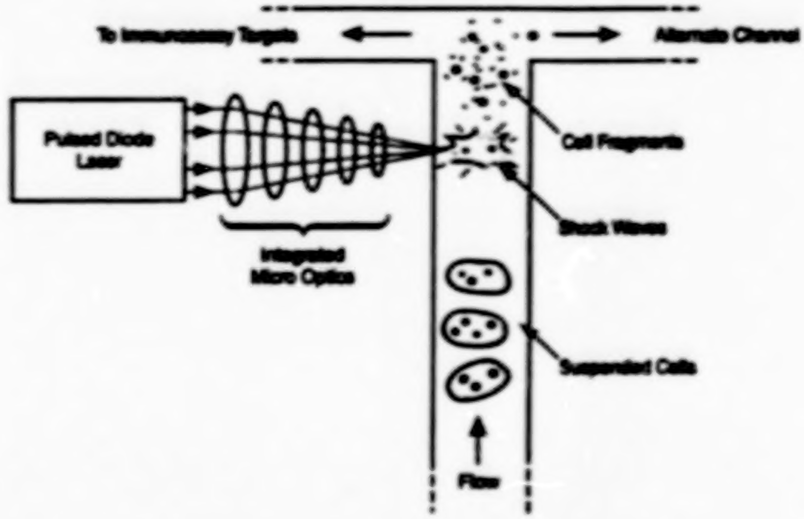
Laser-Induced Shock Waves Would Lyse Cells for Analysis

The cost and complexity of analysis would be reduced.

NASA's Jet Propulsion Laboratory, Pasadena, California

According to a proposal, laser-induced acoustic shock waves would be used to lyse cells as needed for biomolecular investigations, including, for example, diagnosis of diseases, pregnancy tests, analyses of genetic molecular structures, and general analyses of cell chemistry. Heretofore, it has been common practice to suspend cells in liquid buffers and to introduce lysing chemicals into the buffers. While chemical lysis is effective, it contributes to the cost and complexity of analysis and creates a problem of disposal of additional chemical waste, especially in situations in which many samples must be analyzed. By eliminating the need for lysing chemicals, the proposed technique would reduce the cost, complexity, and need for post-analysis waste disposal.

In the proposed technique, a sample of cells would be suspended in a liquid buffer as before, but instead of treating the suspension with lysing chemicals, the suspension would be pumped through an optically accessible channel. The beam from a pulsed diode laser would be focused into the channel (see figure). The energy deposited locally in the buffer by the focused pulses would be sufficient to induce acoustic shock waves, which would lyse cells in or near the focal spot.



A Pulsed, Focused Laser Beam would induce acoustic shock waves in a liquid buffer. Cells suspended in the buffer would be lysed by the shock waves.

This work was done by Robert Stirbl and Philip Moynihan of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

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Refer to NPO-30410, volume and number of this NASA Tech Briefs issue, and the page number.

Improved Technique for Detecting Endospores via Luminescence

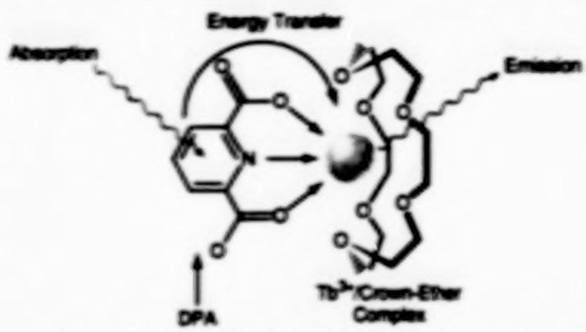
The sensitivity of detection is increased by a factor of about 10^3.

NASA's Jet Propulsion Laboratory, Pasadena, California

A technique for detecting bacterial endospores via luminescence affords a sensitivity much greater than that of a prior luminescence-based technique from which it is derived. The advantage of luminescence-based detection is that the entire preparation-and-detection process takes only minutes, whereas a conventional process of culturing cells, staining cells, and examining cells under a microscope can take hours or days. The present technique could be especially useful for environmental monitoring of pathogenic bacterial endospores.

In the prior technique, one prepares a sample by adding a great excess of $TbCl_3$ to an aqueous suspension that contains bacterial endospores. The Tb^{3+} ions formed by the dissolution of $TbCl_3$ interact with H_2O to form $[Tb(H_2O)_9]^{3+}$ complexes. A typical bacterial endospore contains between 2 and 15 weight percent of dipicolinic acid (DPA). The $[Tb(H_2O)_9]^{3+}$ reacts with DPA released from the spore casing to generate a monochelate $[Tb(DPA)(H_2O)_6]^{+}$ complex. Particles are removed from the suspension by use of a 0.22-µm filter. Under ultraviolet illumination at the wavelength of maximum absorption in DPA, the $[Tb(DPA)(H_2O)_6]^{+}$ luminesces with an intensity greater than that of $[Tb(H_2O)_9]^{3+}$. The intensity of luminescence can be measured and used to estimate the concentration of spores by reference to a calibration curve of intensities measured previously at known spore concentrations.

The main limitation on sensitivity of detection arises from the need for the great excess of the concentration of terbium over that of DPA. Excess terbium ensures that out of three Tb chelates that can exist in equilibrium, the one that predominates is the desired monochelate $[Tb(DPA)(H_2O)_6]^{+}$. The photophysical properties (e.g., quantum yield and luminescence lifetime) of the other chelates are such that if allowed to remain in significant quantities, they would detract from the measurements. Unfortunately, the great excess of Tb needed for forming monochelates also leads to a large, undesirable background luminescence attributable to unchelated Tb^{3+}, with consequent adverse effect on detection. Moreover, coordinated water molecules contribute undesired efficient nonradiative



A Single DPA Molecule can enter the coordination sphere of a Tb^{3+}/crown-ether complex. The DPA absorbs ultraviolet light, some of the energy of the absorbed light is transferred into the complex, and photons containing some of the transferred energy are emitted. These photons are detected to obtain a measure of the concentration of spores from which the DPA molecules were released.

decay pathways that drastically reduce the quantum yield of luminescence, with consequent further adverse effect on detection.

The present improved technique is based on the idea that if it were possible, it would be preferable to have Tb in slight excess to reduce the background luminescence attributable to unchelated Tb^{3+} while simultaneously preventing the equilibrium formation of the undesired chelates and eliminating coordinated water. In this technique, the analysis reagent is a supramolecular complex that comprises a central lanthanide ion (which could be Tb^{3+}) caged by a crown ether. The six oxygen atoms in the crown ether occupy most of the coordination sites of a lanthanide ion. A light-harvesting DPA molecule can enter this complex at the remaining coordination sites and be detected by luminescence emitted in an absorption/energy-transfer/emission (AETE) process (see figure). The configuration of occupied and unoccupied coordination sites of the Tb^{3+}/crown-ether complex is such that only one DPA molecule can bind to it and the complex contains no coordinated water. Relative to the prior technique, the elimination of coordinated water multiplies the sensitivity of detection by a factor of about 10, and the reduction of background luminescence multiplies the sensitivity by another factor of 100, yielding overall improvement of a factor of about 10^3.

This work was done by Adrian Ponce and Kasthuri Venkateswaran of Caltech for **NASA's Jet Propulsion Laboratory.** *Further information is contained in a TSP (see page 1).*

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